Vol. VIII
No. 3

Monograph Supplements

June, 1907
Whole No. 34

THE

Psychological Review

EDITED BY

J. MARK BALDWIN
JOHNS HOPKINS UNIVERSITY

HOWARD C. WARREN
PRINCETON UNIVERSITY

AND

CHARLES H. JUDD
YALE UNIVERSITY
(*Editor of the Monograph Series*)

Yale Psychological Studies

New Series Volume I No. II

EDITED BY

CHARLES H. JUDD
*Professor of Psychology and Director of the Psychological Laboratory,
Yale University.*

THE REVIEW PUBLISHING COMPANY
41 NORTH QUEEN ST., LANCASTER, PA.,
AND BALTIMORE, MD.

AGENTS; G. E. STECHERT & CO., LONDON (2 Star Yard, Carey St., W. C.);
LEIPZIG (Hospital Str., 10); PARIS (76 rue de Rennes).
MADRID: DANIEL JORRO (Calle de la Paz, 23).

EDITOR'S PREFACE.

This issue of the Yale Psychological Studies completes the first volume of the New Series.

Mr. Charles H. Smith, the Mechanic in the Laboratory, drew a number of the figures used in the papers here published and also constructed various pieces of apparatus used in these investigations.

TABLE OF CONTENTS.

TONAL REACTIONS.

EDWARD HERBERT CAMERON, Ph.D.,

Instructor in Psychology, Yale University.

I. Introductory; Description of methods that have been used in studying tones.

II. The method of this investigation was the tracing upon smoked paper of vibrations from the voice which were transmitted by means of a diaphram to the smoked paper.

III. Preliminary tests of this method.

IV. Accessory apparatus for producing standard tones. Organ pipes were used for these tones.

V. Summary of previous investigations of distractions.

VI. Results of experiments.

Series I. The attempt to sing a uniformly sustained tone is not successful. The pitch varies from moment to moment. The beginning of the tone is markedly irregular and there is a tendency to raise the pitch towards the end of the tone.

Series II. Maintaining a tone uniformly with short intervals of rest gives results similar to those of Series I.

Series III. Imitating standard tones shows different degrees of ability in different individuals and in the same individual for different tones. There is a general tendency to sing higher than the standard.

Series IV. Imitating tones as above with organ pipes sounding as distractions results in departures sometimes in the direction of the distracting tone, sometimes in the opposite direction. There is usually a harmonious relation between the sung tone and the distracting tone.

VII. Discussion of results.

I. Introductory.

The voluntary production of vocal tones involves at once the recognition of a series of sensory impressions and a highly developed reaction to these sensory impressions. Even so simple a process as that of maintaining or repeating the simplest tone calls for a constant control of the vocal organs and a constant exercise of some degree of active attention. The investigation of vocal production of tones is, accordingly, important for two reasons. In the first place such an investigation will throw light on the relation between the type of reaction and sensation involved in articulation, and in the second place a

contribution can be made to the solution of the general problem of the nature of active attention.

Many methods have been used for the study of vocal tones. The following summary of some of the chief methods employed may serve as an introduction to the description of the method used in the present investigation.

Scott's[1] phonautograph consisted of a large trumpet closed at one end by a thin membrane connected with a small recording lever. The vibrations communicated to the air from the voice were transmitted by means of the membrane and lever to the smoked surface of a revolving drum. Various forms of apparatus not differing essentially from Scott's have been since devised and the apparatus used in the present study is a modification of the same principle.

An important modification of the phonautograph was made by Blake,[2] who removed the difficulty due to the inertia of the levers and the friction of the recording point by attaching a small mirror to a telephone plate and photographing the ray of light deflected from a heliostat. The well-known manometric flame has also been photographed for the purpose of investigations in the field of phonetics.

An apparatus of a somewhat similar kind was devised and used by Hensen[3] to demonstrate the constancy in pitch with which a sung tone can be maintained. The flame from a manometric capsule was reflected in a mirror attached to the end of one prong of a vibrating standard fork. A tone sung into the capsule with the same frequency as the fork causes the flame to reflect but one point in the mirror. The octaves 2:1 and 3:1 reflect two and three points respectively. Other ratios make the flames appear twisted together, the number of points varying with the ratio. Thus, the ratio 3:2 has three points and the ratio 4:3 four points. A slight variation in the pitch causes the figures in the mirror to rotate around a vertical

[1] Scott, *Inscription automatique des sons de l'air au moyen d'une oreille artificielle*, 1861.

[2] Blake, The use of the membrana tympani as a phonautograph and logograph, *Archives of Opthal. and Otol.*, 1876, Vol. V., No. 1.

[3] Hensen, 'Ein einfaches Verfahren zur Beobachtung der Tonhöhe eines gesungenen Tons,' *Arch. für Anat. und Physiol.* (Physiol. Abth.), 1879, p. 155.

axis, the rate of rotation depending upon the amount of variation. If the sung tone is lower than the standard tone, the flame appears to move in the direction in which its tips are pointing; if too high, it appears to move in the reverse direction.

Klünder's[1] method for determining the accuracy with which a tone can be reproduced by the voice was to obtain records from the voice and an open organ pipe simultaneously. The record from the pipe and that from the voice were obtained by means of two phonautographs so situated that the two records were made side by side on a smoked paper. The number of vibrations from the organ pipe was then compared directly with the number made by the voice during the same time. By this somewhat rough method of comparison, Klünder found an average error in pitch of from $\frac{4}{10}$ of 1% to $1\frac{1}{2}$% in tones sung under favorable conditions by several persons who were trained musicians.

Among the more recent methods of studying the pitch of tones is Seashore's[2] tonoscope. This apparatus is constructed on the same principle as the stroboscope, the vibrations being made visible on the moving surface of a drum, by the action of intermittent flashes of light from a manometric flame. The drum is covered with white paper, on the surface of which are parallel rows of equidistant dots. The first row has seventy-three dots and each succeeding row contains one more than the last.

The speed of the drum is regulated so that intermittent flashes of light of the same frequency as a standard tone cause one of the lines of dots to appear as if standing still. The sung tone is then projected on the screen by means of intermittent flashes from a manometric flame. The pitch of the tone is indicated as before by the number of dots in the line that appears to stand still. The sung tone can thus be compared with the standard tone.

[1] Klünder, 'Über die Genauigkeit der Stimme,' *Arch. für Anat. und Physiol.* (Physiol. Abth.), 1879, p. 119.

[2] Seashore, 'A voice tonoscope,' *University of Iowa Studies in Psychology*, 1902, Vol. III., p. 18.

While the tonoscope has the advantage of presenting to the subject the visible results of the tone while it is being sung, and also of facility in reading, it has on the other hand the disadvantage of giving only an approximate result. The pitch not being uniform for even very short periods of time, it is necessary to select the predominating pitch.

II. Apparatus.

The recording apparatus used in the present investigation consisted of a round rubber telephone receiver, a vertical cross section of which is represented in Fig. 70. The box

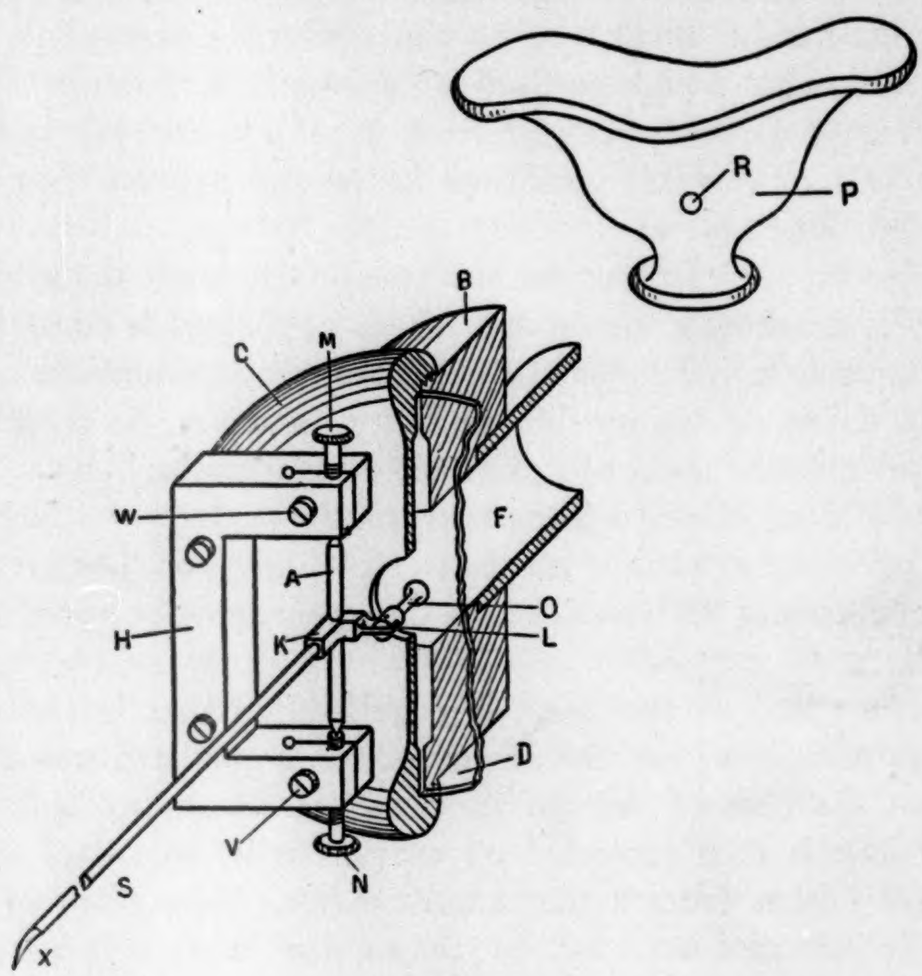


Fig. 70.

(*B*) is provided with a cover (*C*) of the same material which may be screwed tightly to the face of the box. Between the front edge of the box and the cover is a diaphragm (*D*) of thin mica, which is held firmly in position by the cover, when

screwed down. The diaphragm is 5.3 cm. in diameter. Glass diaphragms have also been used, but with less satisfactory results.

The cylindrical chamber (*F*) communicates directly with the air chamber back of the diaphragm. An aluminum mouthpiece (*P*) is attached to the outer edge of (*F*) by a small piece of rubber tubing. In the later experiments a long flexible tube was substituted for this form of connection between (*F*) and the mouthpiece (*P*). A small hole (*R*), 3 mm. in diameter, is bored in the mouthpiece to allow the escape of the air forced into the chamber at the moment the tone is sung.

There is screwed to the front of the box a piece of brass (*H*), shaped as shown in the figure, and used for the purpose of holding the adjustable screws *M* and *N*.

M and *N* are held securely in position by the set screws, *V* and *W*. *M* and *N* are fitted with jewel bearings in which play the tapering ends of the steel axle *A*.

To the axle is attached the aluminum right-angle piece *KL*. *K* carries a straw (*S*) to the end of which is fastened the recording point *X*. This point is made of hammered brass, carefully cut to a point and polished. Such a point is fine enough to make a sharply defined line on smoked paper and the lamp black does not adhere to it.

The other arm *L* is attached by a joint to a smaller link (*O*) of aluminum which passes through an opening in the middle of the box cover, and is fastened to the center of the diaphragm by a drop of glue.

There is thus provided a system of continuous levers from the outer surface of the diaphragm to the recording point, so that movements of the diaphragm caused by the singing of tones into the mouthpiece or by any other means are magnified, and may be recorded on a belt of smoked paper. Since it is desirable to obtain very long series of records a long belt of smoked paper is used. The belt passes between two drums placed fifteen feet apart. It is smoked at one of the drums and after the record is made is shellacked from behind.

A portion of a typical record obtained in this way is shown in Fig. 71. The upper line (*A*) of the figure is the time line

obtained from a marker connected with a Kronecker interrupter, set to mark periods of 100 sigmas. The lower line consists of vibrations from the voice transmitted through the diaphragm.

Fig. 72, page 233, shows the apparatus used for reading the record. It consists of a cast iron base (*A*), 41 cm. long by 16 cm. wide, fitted with a T-shaped slot, into which fits the T-shaped piece, *B*, of the same material. The top surface of *B* is 9.5 cm. wide, its width being a little greater than that of the glazed paper used for the records.

The record (*C*) is placed upon (*B*) and held in position

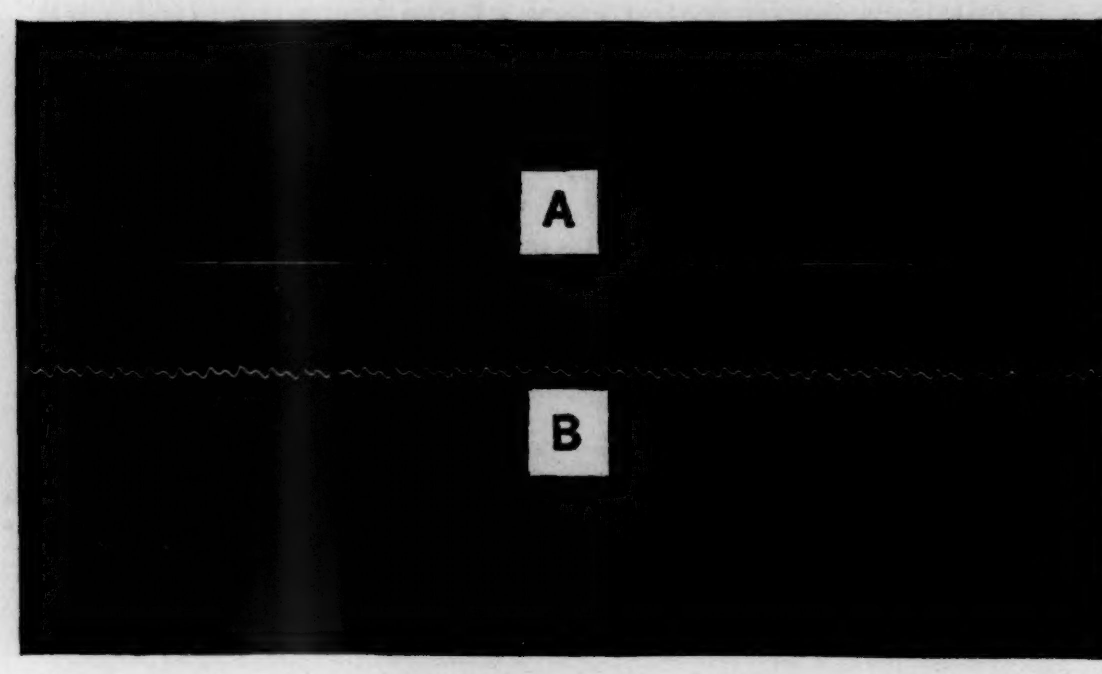


FIG. 71.

by the brass strips, *D* and *E*, which are in turn held in position by the thumb screws, *H, H, H, H*. The inner edges of these brass strips are notched, the tooth-like projections being very accurately spaced, and so placed that the line drawn between any one of the points on the one side to the corresponding point on the other side is exactly parallel to the line of direction in which B moves as it slides in the grooves. The brass gib, whose end only is represented by the dotted line *J*, prevents any loose motion in *B* and still allows perfect freedom of sliding in the base *A*.

M and *N* represent pieces of transparent celluloid, one and

one-half millimeters in thickness, their under surfaces being parallel to that of *B* and at such a level as to just allow for the thickness of the record paper between *B* and the celluloid pieces. On the under surface of *M* and *N* near their inner edges are drawn fine hair lines, *S* and *T*, perpendicular to the line of motion of both *B* and the celluloid plates. The lines were scratched into the surface of the celluloid with a sharp-pointed knife. The inner edges of the celluloid pieces are bevelled to prevent refraction. These celluloid pieces are screwed to T-shaped carriages of bronze which slide in a groove in the metal base, their line of motion being parallel to that of *B*. The brass nuts *P* and *R* are also attached to these strips and the movement of *M* and *N* in either direction is accomplished by the turning of the screws *X* and *Y*.

The screws *X* and *Y* are accurately turned, the distance between the threads being two millimeters. *V*, the head of the screw *Y*, is graduated into forty equal divisions and numbered as shown in the figure.

The record (*C*) is laid upon the surface of *B* and the brass strips *D* and *E* placed over it. The time line *I* is brought exactly underneath one of the tooth-like projections at one end and a corresponding portion of the time line *F* is placed under the corresponding tooth on the other side.

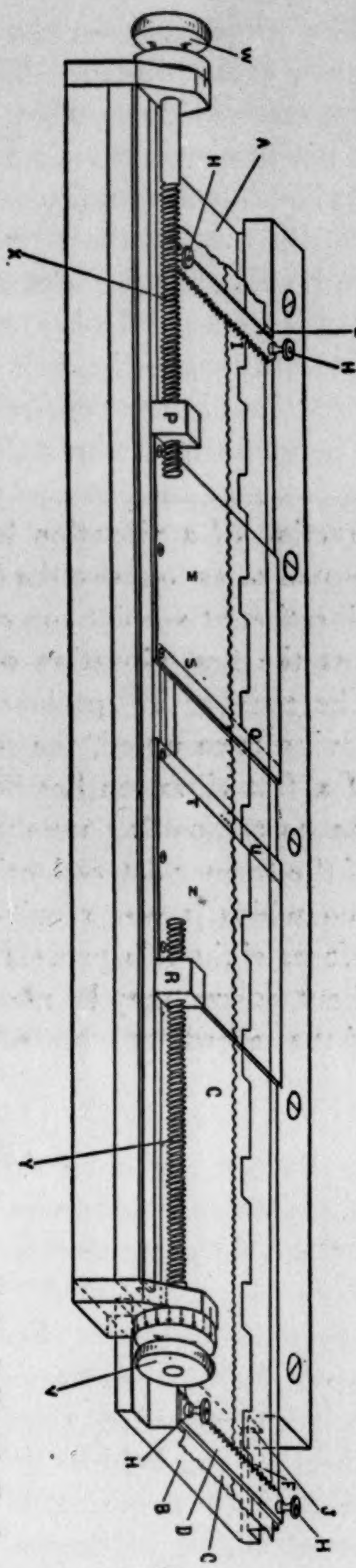


FIG. 72.

The projections on the brass strips being numbered, this is easily accomplished. When this has been done, the brass strips are screwed down upon the record, which is thus kept in such a position that the time line is parallel to the line of motion, and is thus perpendicular to the hair lines *S* and *T*.

By turning the screws (*V*) and (*W*) the hair lines (*S*) and (*T*) may be brought so as to cut corresponding points, such as (*O*) and (*U*), in two successive vibrations of the time line. Suppose the hair line at the left cuts one of the tone vibrations in the depression of a wave, as shown in the figure. The number of whole vibrations occurring during a tenth of a second may then be easily counted. In order to determine the fraction of a vibration left over, the screw (*V*) must now be turned so as to move the hair line (*T*) till it cuts the last whole vibration at a point corresponding exactly to that at which (*S*) cuts the first vibration of the period which is being counted. The number of graduations through which (*V*) has turned having been noted, the screw should be turned until the space of a full vibration has been traversed by the hair line *T*, and the corresponding number of graduations noted. The ratio of the former determination to the latter is the fractional vibration which it was required to measure. By sliding *B* to the left or right this process may be repeated so that a length of about 30 cm. may be measured without making a readjustment of the record.

III. Preliminary Tests of the Recording Apparatus.

Before beginning the experiments on vocal tones, a series of preliminary tests was made with physically produced tones for the purpose of determining the accuracy with which the diaphragm responded to air-vibrations, and recorded small differences in pitch. For this purpose a 100 V.D. electrically driven tuning-fork was used. To the end of one prong of this fork was attached a small mica disc. The fork was set in vibration and held so that the disc was in front of the mouthpiece of the diaphragm. The same 100 V.D. fork was connected with a marker which recorded its vibrations upon the smoked paper belt parallel with the diaphragm lever. At the

same time another marker recorded tenths of seconds from the Kronecker interrupter. There was thus obtained side by side a record of the vibrations of the fork as transmitted by the diaphragm, and one directly through a marker from the same fork. By means of the time line from the Kronecker interrupter these two records could be compared with absolute time as well as with each other. It was found in all instances that the frequency of the vibrations of the two records from the 100 V.D. fork corresponded exactly, thus showing that the diaphragm did not modify the rate of the air-vibrations. No account was taken in any of the experiments of the differences in the form of the vibrations. Since these differences are also neglected throughout the investigation it is not necessary for us to enter into a discussion of their character here.

By weighting the prongs of the fork, the sensitiveness of the diaphragm in responding to small differences in the rate of vibration of the impinging waves was tested. The weights were moved backward and forward upon the prongs of the fork, the changes thus made causing small differences in the rate of vibration of the fork. All these small differences were found to be transmitted to the record. Differences of less than one vibration per second were thus recorded. All these tests were repeated, using a 250 V.D. fork and with similar results.

Comparison of the different parts of the record thus obtained from a fork was also made, with the result that in each case the record showed the uniformity of the pitch of the tone at different points throughout its length. This test was also made with organ pipes and special attention given to the beginning of the tone which will be shown later to be a variable part of sung tones. In no case was there found to be any difference between the frequency of vibration at the beginning of the record and at other points throughout its length. We are, therefore, fully justified in concluding that the inertia of the recording point due to friction was a negligible quantity.

IV. Accessory Apparatus.

A series of physical tones was necessary for various parts of the experiment. These were obtained by using a series of

labial organ pipes made of metal and wood. The metal pipes were taken from the open diapason stop of an organ and were selected because of the comparative ease with which they could be imitated by the human voice. The number of pipes was twenty-five, comprising the two octaves D♯ (302.8 vib. per sec.) to D♯ (75.5 vib. per sec.), including half tones. Sixteen higher pipes ranging from D♯ downward to C were of zinc and were open pipes. The remaining nine, comprising the lower notes from B to D♯ were closed wooden pipes. The qualities of the two kinds of pipes were not markedly different, the combination being similar to that which is often used in the same stop of small pipe organs.

The air supply for blowing the pipes was obtained from a tank situated in the basement of the laboratory, and was conducted to the research room by means of iron pipes. The tank was supplied with a high pressure of air by means of an air pump, which was operated by the engine of the work-shop.

As the pressure of the air thus supplied was very great and inconstant (10 to 60 lbs. per square foot), an arrangement was necessary to give a steady supply of air at moderate pressure. This was obtained by means of a reservoir provided with a valve which permits a regulation of the air supply. The reservoir consists of two galvanized iron tanks (*A* and *B*, Fig. 73). The smaller tank is placed, bottom upwards, within the larger tank. The wheels *C* keep the upper tank in a vertical position and prevent friction between the sides of the tanks.

Two iron pipes pass through the sides of the larger tank near the bottom and turning upward end almost at a level with the top of the tank. One of these pipes *E* is connected with the air chamber, which communicates directly with the organ pipes; the other *D* is connected with the air supply through the valve *H*.[1]

This valve is opened and closed by the lever *K*, air being allowed to enter when *K* is depressed and being cut off when

[1] During the experiments here recorded, this valve (*H*) was opened and closed by hand. The automatic regulating device shown in the figure has since been added.

K is raised. To the end of *K* is attached the cord *L*. The cord passes over the pulleys *M* and *N*, which are attached to a horizontal beam above the tanks, and is fastened at its other

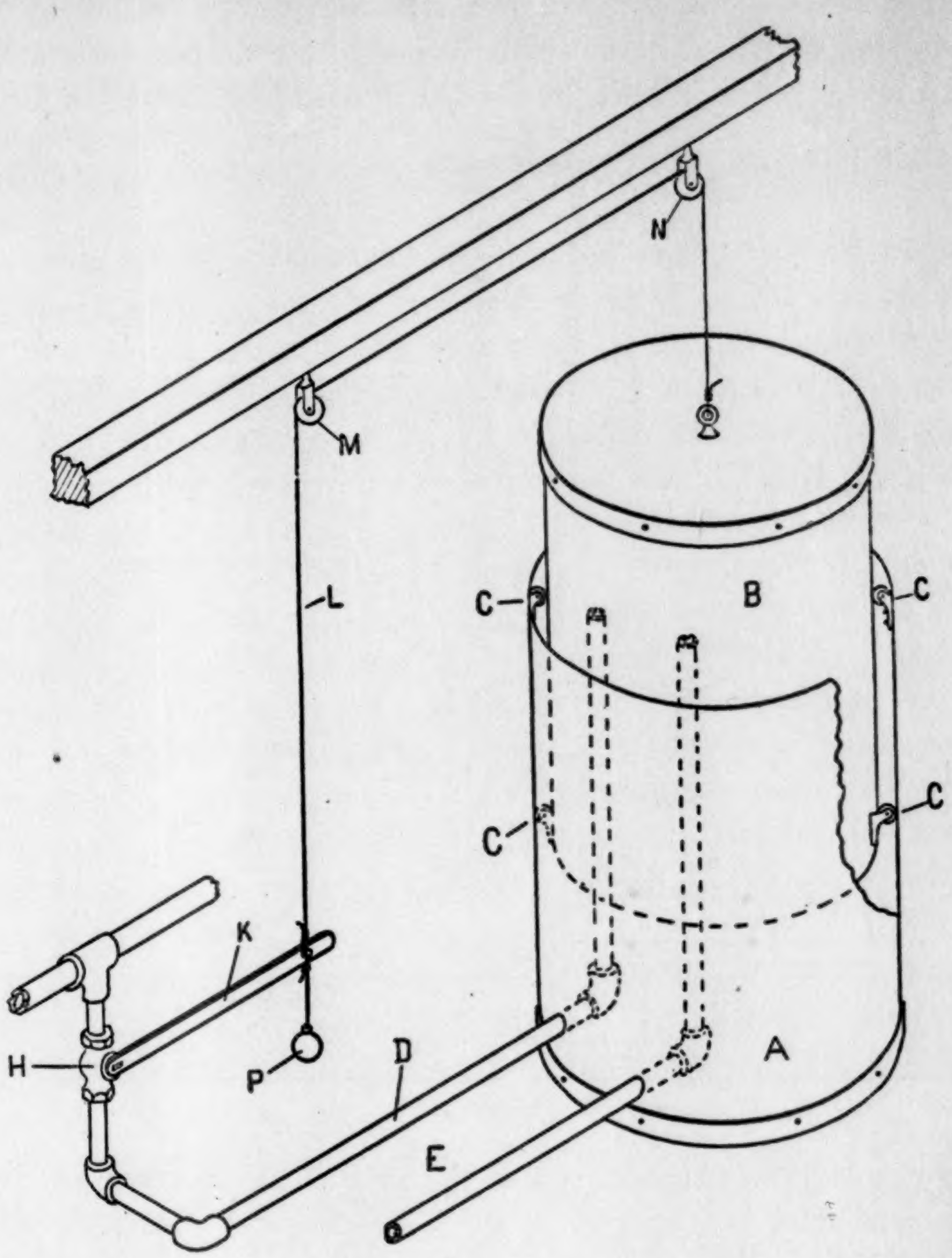


FIG. 73.

end to the upper tank. The small weight *P* suffices to pull the lever *K* down when the tension on the cord is relaxed.

The lower tank is filled with water to a point which is above the level of the uppermost position of the mouth of the upper tank. Air is now admitted from the supply into the

tank *B*. It gradually rises like an ordinary gas tank until the valve *H* is automatically closed.

The air may be drawn off through the pipe *E* for any purpose desired, and the reservoir is automatically refilled by the opening of *K*. There is thus furnished a continuous stream of air under constant pressure for use in sounding the organ pipes.

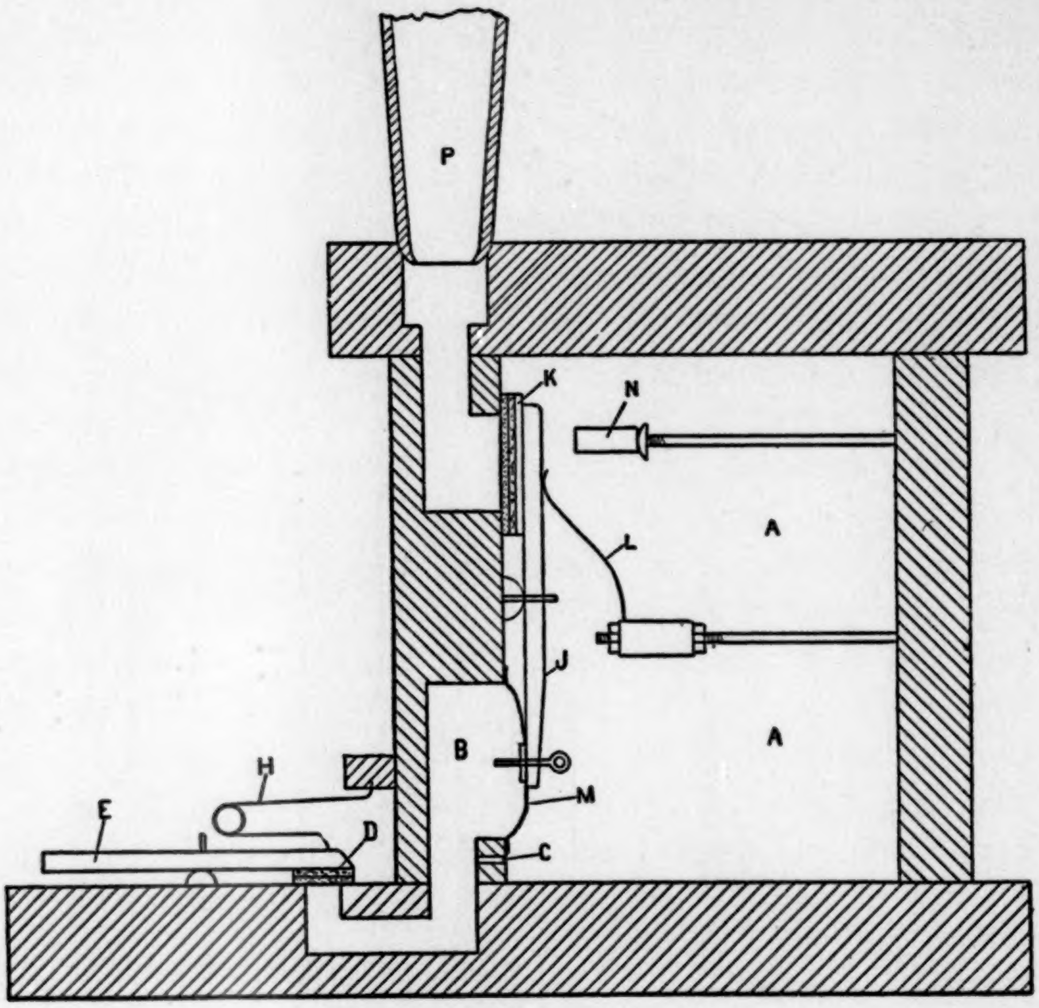


Fig. 74.

By varying the weights used on the tank *B,* the pressure of the air used may be changed at will. During the course of this investigation, the air in the tanks was kept at a fixed pressure of about 15 pounds to the square foot.

The organ pipes were sounded by means of a series of keys and an air chest supplied to the laboratory by Hall & Co., organ builders. Fig. 74 represents a cross section of the air chamber, communicating directly with the organ pipes, and supplied with air through pipe *E* (Fig. 73). The

air is introduced directly into the main air chamber *A*, and part of it escapes through the small hole *C* into the smaller chamber *B*. The latter may be made to communicate with the outer air if the valve *D* is opened. This may be done by pressing the key *E*. Unless the key is pressed at *E* the spring *H* keeps the valve *D* closed. The valve is made of a layer of sheepskin and a layer of felt and the pressure of the spring is thus sufficient to effectually close the opening to the passage of the air.

A similar key *J* controls the passage of the air to the pipe *P*, through the valve *K*. In order to open *K*, the tension of *L* must be overcome and the lower end of the key *J* must move into the chamber *B*, carrying with it the flexible sheepskin partition *M*. If now the valve *D* is closed, the valve *K* is also kept closed by the spring *L* and also by the fact that the pressure in the chamber *A* is greater than atmospheric pressure in the pipe *P*. If, however, *D* is opened, the pressure of the air in *B* is much reduced, since the air escapes much more rapidly through *D* than it can pass through the small hole *C*. As the pressure in *A* remains practically the same, the flexible partition *M* attached to the lower end of *J* is pressed into chamber *B*, overcoming the pressure of *L* and opening the valve *K*. The adjustable post *N* keeps the key from going back too far when released, and thus prevents excessive strain on the spring which is also adjustable.

A simple pressure of the key *E*, therefore, serves to release the air from *A* and sound the pipe. The whole contrivance provides a convenient and simple means for this purpose, and makes use of the air pressure to obtain a quick and noiseless opening of the valve leading to the organ pipe. Each pipe is provided with a separate set of valves of the type described, all opening, however, into the same chamber *A*.

Before beginning the experiments the pipes were carefully tuned. The pitch of each pipe was then determined by recording its vibrations through the diaphragm described above, and measuring their frequency by means of the time line from the Kronecker interrupter. In order to avoid changes in pitch due to variations in temperature, the air of the room

was regulated to 70° F., and in subsequent experiments care was always taken to have the air of the room at this temperature. In making the tests, changes in temperature in the pipes due to handling were avoided by holding them in position by means of cords. Some of the pipes were tested later and no difference in pitch was detected.

The results of the test of the pitch of the pipes were as follows:

VIBRATIONS PER SECOND.

D♯	D	C♯	C	B	A♯	A	G♯	G	F♯	F	E
302.8	286.4	271.8	255.4	240	225	214	200	187	178.1	170	160
152.4	144.2	135.6	126.6	120	112.1	107.1	100	93.7	88.5	85	80
75.5											

V. Summary of Previous Investigations of Distraction.

With the apparatus described it was possible to study the vocal reaction under a variety of conditions. First, in order to lay the foundation for the treatment of all the later questions, an investigation was made of the type of reaction involved in holding a simple tone. Second, the reactor was required to imitate a tone which was sounded in his ear by the organ pipes. Third, the subject imitated a tone in this way, and at the same time another tone from the organ pipes was sounded in order to test the effect of such a distraction.

Before reporting the results of these investigations, it will be advantageous to summarize briefly certain of the investigations of attention which indicate the wide variations produced in different cases by distractions. The methods of measuring the effects of distraction are various, some investigators using reactions and others using comparison of sensations. The general result is, however, that distractions may produce deviations from the normal in every possible direction. This will come out with all clearness in the following summaries.

In connection with his work on reaction-time and attention Bliss[1] made a number of experiments which showed the influence of disturbances of the attention upon the voluntary control of arm muscles. This was done by making a graphic record

[1] Bliss, 'Investigations in reaction-time and attention,' *Studies from the Yale Psychological Laboratory*, Vol. I., p. 1.

of the accuracy with which a person can point steadily to a given spot. The irregular shape of the curve showed that there was a constant movement of the finger above and below the spot. When a strong distracting stimulus was given the control of the muscles was still more uncertain. If the disturbance was slight, however, the added stimulus seemed to render the action steadier rather than otherwise.

In Bliss's reaction experiments no difference in time was detected between reactions in silence and those in which the subject was listening to a continuous sound from a tuning-fork of 250 vibrations per second. When the intermittent beats of a metronome were used as a means of distraction, however, the reaction time was lengthened.

Slattery[1] made a study of the relation of the reaction time to variations in intensity and pitch of the stimulus. The reaction time remained practically constant for variations in intensity, but a decrease in the time of reaction was noted corresponding to the rise of the pitch of the tones used as stimulus.

Swift[2] reported experiments with respect to simple reactions and choice reactions with and without distractions. Distractions were found to lengthen the time of the reactions in both cases. When the distractions were made up of stimuli of the same kind as those to which the reaction took place, there was more disturbance than when the distraction and stimulus were from different senses.

In the PSYCHOLOGICAL REVIEW,[3] 1894, Münsterberg has an article on the intensifying effect of attention in which he reports the results of a series of experiments carried out in the Harvard Laboratory. The object of the experiments was to find out whether it is true, as usually held, that "when the attention is directed to objects of sense, its effect is not only to increase the clearness and liveliness of the impressions, and strengthen the resulting associations in consciousness, but also to intensify the impressions themselves." The experiments

[1] Slattery, 'On the relation of reaction-time to variations in intensity and pitch,' *Studies from the Yale Psychological Laboratory*, Vol. I., p. 71.

[2] Swift, 'Disturbance of the attention during simple mental processes,' *Amer. J. of Psych.*, Vol. I., 1892, p. 1.

[3] PSYCHOLOGICAL REVIEW, Vol. I., pp. 39-44.

were arranged in such a way that the intensities of the two impressions of moderate strength could be compared, and at the same time the attention directed toward one and away from the other. The distraction was effected by directing the subject to add numbers before and during the time in which the stimulus was given. In this way four series, as follows, were arranged for each group of stimuli studied: (1) Attention was directed without distraction to each of the two stimuli; (2) attention was directed to the first stimulus but diverted from the second; (3) attention was directed to the second stimulus but not to the first; and (4) attention was distracted when both stimuli were given. These experiments gave the unexpected result that all stimuli appear relatively less when the attention from the outset is directed to them. Münsterberg explains his results by attributing the effect to muscular tensions accompanying the process of attention. As in the well-known weight illusions, "if the sensations of tension be relatively strengthened by expectant attention, the stimulus will appear weaker than if the stimulus itself were to arouse reflexly all the corresponding muscular tensions."

Another series of experiments was made by Hamlin[1] along the same line as Münsterberg's for the purpose of verifying or disproving the earlier results. These experiments proved to be chiefly valuable in pointing out the shortcomings of the method used for distracting the attention. Out of fifteen cases only two showed the maximum of correct judgments in the series without distractions. In six cases the greatest accuracy was reached when the distraction occurred during the time of the first stimulus, and in four cases with distraction throughout. From the introspective evidence these results were interpreted as being due to the fact that the distraction acted as a spur rather than a check to the process of attention. This was possible because addition is not a continuous means of distraction. It was further shown that the duration of the attention is not so significant for accuracy of judgment as the degree of attention. While the distraction brought about by the adding proc-

[1] Hamlin, 'Attention and distraction,' *Amer. J. of Psych.*, Vol. VIII., 1896, p. 3.

ess shortened the duration of the attention, it also afforded, on account of its lack of continuity, brief periods of attention accompanied by a heightened degree of interest.

Following these experiments of Hamlin's a series of tests was made in the Cornell Laboratory dealing with the relative value of different stimuli for the purpose of distractions. The aim was "to discover a reliable measure of the attention by means of some form of distraction which should at least possess the qualities of (1) capability of gradation; (2) continuity; and (3) possibility of general use with normal subjects."

The first of the series of studies is reported by F. E. Moyer.[1] It is concerned with the value of various forms of distractions in connection with the discrimination of various shades of gray, and of the relative intensity of two sounds produced by the falling of ivory balls upon ebony plates. The conclusions reached were that addition, writing words of a sentence in a reverse order, translating into a foreign language, and similar forms of distraction cannot be relied upon to produce the required result. They do not affect all persons alike, nor even the same person at different times and often have no disturbing effect whatever. Of the means tried, odors gave the best results. In all cases the effect of distraction was much heightened when interest in the experiment aroused a strong affective tone in the subject.

L. G. Birch[2] continued the work begun by Moyer and made a more thorough investigation into the value of odors as means of distraction. Fifty scents used to distract the attention in connection with the discrimination of sound intensities of two stimuli decreased the number of right judgments from fifty to no per cent., and in some cases caused an actual increase of the number of right determinations. A table of odors was arranged in the order of their distracting power. It was inferred from the results that distraction in connection with odors may arise in four ways: "by familiar scents that cannot be named; by very familiar, and therefore suggestive, odors

[1] Moyer, 'A study of certain methods of distracting the attention,' *Amer. J. of Psych.*, Vol. VIII., 1897, p. 405.

[2] Birch, 'Distraction by odors,' *Amer. J. of Psych.*, Vol. IX, 1897, p. 45.

(attention on the odor); by unfamiliar, and therefore puzzling, scents; and by easily recognizable scents, whose recognition suggests that the whole experiment is over." Familar scents and uncertainly familiar scents are the least distracting.

Darlington and Talbot[1] carried out experiments to determine the relation between the pitch of a musical note and its distracting power, and in general the value of a musical phrase as a distraction. Music proved to facilitate the attention in connection with the relative estimation of lifted weights, both when played throughout the experiment, and when played in one half only. Very little, if any, connection was discovered between pitch and distracting power.

F. Angell[2] used a number of the above mentioned means of distraction in his experiments on the discrimination of clangs for different intervals. In addition, he used the methods of reading, and listening to interesting literature, and discriminating clangs differing by a small interval. These latter means of distraction were found to be more absorbing than uninteresting and partially mechanical processes like addition and counting metronome beats. Taking into consideration all forms of distraction the accuracy of judgment was increased in two-thirds as many cases as it was decreased, and in a few instances the distractions had no effect. Further, there was little indication that the absorbing character of the distraction, as determined by the subjective attitude of the person observed, was accompanied by a corresponding decrease in accuracy of judgment. On the contrary, it was when the less absorbing forms of distraction were used that the least number of right judgments was recorded.

From the results of these and the preceding investigations, it will be seen that the use of a stimulus to distract the attention may have any of three different results. It may, in the first place, be apparently completely ignored; or, in the second place, it may reinforce the attention; or, lastly, it may divert the attention to the distraction. Distraction is, accordingly, not

[1] Darlington and Talbot, 'A study of certain methods of distracting the attention,' *Amer. J. of Psych.*, Vol. IX., 1898, p. 332.

[2] Angell, F., 'Discrimination of clangs for different intervals of time,' Pt. II., *Amer. J. of Psych.*, Vol. XII., 1900, p. 58.

to be treated as in every case a negative factor. Indeed, it will be shown by the following results that the most productive conception of distraction is one which treats it as an added factor in a general system of conscious processes. As such an added factor it will operate to destroy the earlier state and will lead to a reconstruction of the whole process. The outcome of this reconstruction when compared with the original state may be either positive or negative or in some cases equal.

VI. Experiments.

Series I. Maintaining Sung Tones.

The subjects who were tested in the following experiments were Messrs. Cockayne, Cowling, Ferris, Freeman, Gifford, Porter and Judd. All were familiar with laboratory methods in psychology and practiced in introspection. Hereafter the names of the subjects will be abbreviated in this paper to Ce., Cg., Fs., Fn., G., P. and J., respectively.

It may be of importance to indicate in a general way the natural musical ability and training of each of these subjects, since the singing of a tone is dependent to so great a degree upon these qualities.

Subj. J. has had no musical training and never attempts to sing except in unison with others.

G. and Cg. have also had no training in music. They, however, have no difficulty in carrying tunes and frequently take part in singing when it is carried on in unison with others.

Fn. and Ce. have had no extensive training, but have more than ordinarily good voices, and read simple music.

P. and Fs. have had special training in singing. The latter also plays the pipe organ.

In the first series of experiments the purpose was to ascertain the ability of the subject to maintain the pitch of a tone uniformly. No attention was paid in any of the experiments to other features of the record than the pitch of the tone sung. Differences in the height and form of vibration were neglected.

Each subject was asked to sing three tones and continue singing them for a moderately long period of time. The

directions given with regard to the pitch of the tone were as follows: The subject was asked to sing any tone of medium pitch, a second of low pitch, and a third of high pitch, and to sustain the pitch selected in each case as uniformly as possible throughout the singing. In point of fact the pitch varied with the different subjects approximately two octaves (from 100 to 300 vibrations per second), and the duration of the singing from 8 to 16 seconds.

Tables I. to VI. present the results of these experiments. Each number in the first column of the tables gives the pitch of the tone for a period of 100 sigmas expressed in terms which show the number of vibrations that would have resulted had the same pitch been maintained for a full second. This means that the number of vibrations actually occurring during that period of time has been multiplied by ten in order to express the pitch in the conventional manner of the number of vibrations per second.

The second and third columns give the averages and the mean variations respectively, calculated in groups of each succeeding ten determinations. A short horizontal line drawn between the figures indicates that they do not represent continuous periods of time. The highest and lowest points in each record are starred in the tables. Some of the typical results are given in the form of curves, Fig. 75, p. 256, in which the abscissæ represent periods of 100 sigmas and the ordinates the frequency of the vibrations. The dotted lines represent the portions of the record which were not read. The average pitch is shown by the continuous horizontal line and the highest point which each tone reached is indicated in addition to the initial tone. Curves *A, B, C* represent Fs.'s tones; *D, E, F* represent Ce.'s tones; *G, H, I* represent Fn.'s tones; and *J, K, L* represent P.'s tones.

TABLE I.

Subject J.

High Tone.

	Av.	M. V.		Av.	M. V.
220*			241.8		
230			241.8		
230			243.6		
235.6			243		
236.2			244	241	1.77
230					
240			243.5		
240			245		
234.2			240		
240	233.6	4.78	240		
			244.4		
235			242.5		
237.7			243.3		
240			245.8		
232.5			245		
238.8			244.4	243.3	1.57
240					
234.4			244.4		
236.8			245		
233.5			244		
233	235.8	2.44	246		
			246		
233			245		
233			247		
230			246.2		
237			246		
236.6			245.5	245.5	.73
237.7					
240			242.2		
238.8			247.5		
240			243.3		
237.7	236.5	2.58	250*		
			247.5		
240			246.2		
237.5			245		
240			243.3		
240			245.5		
234.4			243.7	245.4	1.92
240					
240			245		
240			245		
241			245		
240	239.2	1.39	245		
			246		
240			244		
237.8			247		
240			244		
238.2			246.6		
240			244.4	245.2	.80

Medium Tone.

	Av.	M. V.		Av.	M. V.
130			141		
140			140		
140			142.7		
142.5			141.5		
140			142.9	142.2	.97
142.9					
142.9			142.5		
142.7			143.6		
141			143.1		
140	140.1	2.21	142.6		
			143.8		
143.3			142.2		
140			142.6		
140			142.2		
142.1			140		
140			142.7	142.5	.65
140					
141			142.7		
140			146.6		
141			142.9		
140	140.7	0.9	143.8		
			142.7		
141			143.3		
142.1			142.1		
141			143.1		
141.5			143.5		
141.5			142.8	142.8	.47
143.5					
142.7			141.5		
142.8			143.5		
143			142		
141.5	142	.76	143		
			142.6		
141			143.6		
141.5			145		
139.4			143.3		
142.1			142.7		
141.1			143.3	143.3	.69
143.1					
142.1			143.3		
141.5			143.5		
142.1			144		
141.3	141.5	.67	145		
			144.2		
140			144.5		
142.5			144.5		
142			144.5		
141			143.5		
142.6			143.5	144	.69
141					
142.7			142.5		
141.7			143.6		
142.7			144.1		
142.3	141.8	.75	142.2		
			142.7		
142.9			144.2		
145.2			143.6		
142.5			142.9		
142.3			143.8		
141.7			142.5	143.2	.65

	Av.	M. V.		Av.	M. V.
144.2			143.5		
145.2			144.6		
147			145	144.3	0.6
145					
145.5					
145.5*					
143.6					
143.6					
143.3					
144.6	144.7	.89			

Low Tone.

	Av.	M. V.		Av.	M. V.
105*			115.5		
107.3			115.2		
112.5			115.7		
110			116		
111			115		
110			114.2		
113.5			116.3		
113			116.1	115.4	.67
113					
117.3	111.3	2.6	114.7		
			115.9		
112.6			115.2		
113.1			115.2		
113.3			115.9		
110			115.8		
112.2			115.9		
113			116.6		
114			116.3		
112.8			115.2	115.6	.48
112.7					
111.3	112.5	.83	115.5		
			115.6		
110			114.7		
112			115.3		
112.4			114.7		
110.7			115.3		
112.5			116.6		
112.6			117.8		
112.9			116.6		
114.2			115.3	115.7	.76
113.2					
113.7	112.4	.92	115		
			116		
114.8			116		
113.4			116		
114.5			115.5		
114.8			115.6		
115.8			115.2		
113.5			114		
114.4			116		
114.4			116	115.5	.49
114.7					
114.8	114.5	.57	114		
			114.3		
114.6			115.2		
114.4			116.8		
114.8			117.1		

	Av.	M. V.		Av.	M. V.
115.2			118		
114.1			118		
114.3			116.4		
115.9			116.6		
116.1			117.7	116.4	1.15
116.3					
115	115.	.64	116.1		
			118.2		
116			116.1		
116.6			119		
114.8			119*		
115.9			116	117.3	1.26
115.4					
115.6					
114.6					
116.6					
115.6					
116.6	115.7	.57			

TABLE II.

SUBJECT. FN.

High Tone.	Av.	M. V.	Medium Tone.	Av.	M. V.
230			140*		
230.5			150		
230			146.6		
229.5*			148.4		
230			146.3		
230			146.9		
230.5			148.3		
230			146.6		
230			148.3		
232	230.1	.33	150	147.6	1.86
234			147.3		
232.6			147.8		
235.3			145		
234.7			148.3		
235.5			147.5		
230			148.3		
235.3			147.5		
233.6			148		
234			148.8		
235.3	234	1.19	147.5	148	.68
235.5			148.3		
233.8			145		
233.3			147.3		
234.1			146.2		
238.1*			150		
233.3			147.5		
233.8			147.3		
236.1			145		
234.6			148		
234.6	234.7	1.12	150*	147.4	1.30

Low Tone.

	Av.	M. V.		Av.	M. V.
112.2*			116.8		
120			116.6		
118			117.2		
116.3			116.6		
113.8			115.8	116.2	1.08
112.5			116.8		
115.5			117.5		
114.5			117.5		
118.3			118.5		
117.6	114.8	2.31	118.8		
116.6			116		
120			119		
118.5			117		
116.3			120*		
117.6			119	117.6	1.05

TABLE III.

SUBJECT CE.

High Tone.	Av.	M. V.	*Medium Tone.*	Av.	M. V.
192.7*			115		
206			120		
210			120		
207.9			118.7		
210			114.2*		
207.1			115.8		
210			120		
207.8			118.7		
212.3*			117.8		
207.3	207.1	2.11	118.7	118.1	1.71
210			120		
207.3			117.5		
210			118.1		
210			119.1		
207.6			120		
210			118.5		
208.5			119.5		
207.3			118		
210			118		
208.5	208.9	1.08	120	118.8	.85
210			120		
210			118.5		
208.2			120		
210			120		
211.5			119.5		
210			120		
210			120		
210			120		
210			118.1		
211	210	.43	118.1	119.4	.72
210			118.2		
208.3			120.5		
211.5			122.5		

3

	Av.	M. V.		Av.	M. V.
208.5			121.4		
210			120		
208.5			118.1		
211.5			120		
210			117.9		
210			120		
210	209.8	.95	118.1	119.6	1.29

Low Tone.

	Av.	M. V.		Av.	M. V.
103.9			101		
100			100		
100.9			103.8		
100.9			98.9		
100			101.6		
100			103.8		
101.5			100		
100			100		
101.5	101.2	1.11	101.6		
			102.2	101.2	1.31
101.4			102.9		
99			100		
100.9			101.3		
101.3			101.4		
100			100.3*		
100			101.8		
100.8			100		
100			102.2		
100	100.1	.56	103.3*		
			100	101.1	1.24

TABLE IV.

Subject Cg.

High Tone.

	Av.	M. V.		Av.	M. V.
282.7			284.5		
280			285		
284.3			283.3		
280			283.3		
285.7			284.1		
280			284.1		
285.7			283.6		
284.3			284.1		
282.5			283.5		
285	283.0	1.98	284.4	283.5	.47
286.6			283		
283.3			284		
287*			284		
285			283		
285			285		
284			284		
286			283.9		
288.2			284.2		
285			286		
285.4	285.5	1.11	282.2	283.9	.83

	Av.	M. V.		Av.	M. V.
285			283		
284			282		
285			283		
283.6			282		
285.5			283		
284.5			282		
283.6			282.5		
285			281.1		
283.2			285.5		
286.6	284.6	.87	283.7	282.7	.86

Medium Tone.

	Av.	M. V.		Av.	M. V.
227.5*			243.3		
230			241.8		
228.5			244.1		
232.6			242		
240			243		
240			241		
240			243		
240			241		
240			244		
241.1	235.9	5.07	242	242.5	.86

240			241.8		
242.3			243		
240			241.8		
243.8			242.7		
242			243		
242			243		
242.1			242.7		
242.1			242		
242.7			242		
242	241.9	.78	244	242.6	.56

240			244.5		
242.6			244		
242.1			243		
242.8			243		
240			244		
242.4			243		
242			245		
240			245		
242.3			243		
241.8	241.6	.96	245*	243.9	.76

241.6		
243.1		
242.3		
240		
242.5		
243		
243.3		
243.3		
242.3		
241.5	242.3	.75

Low Tone.

	Av.	M. V.		Av.	M. V.
121*			131		
123.3			130		
125			131		
125			131.7		
125.8			130		
130			130		
123.1			130		
125.3			128.8		
130			130		
126.4	125.4	2.01	130	130.2	.57
125.6			128.8		
123.6			130		
125.5			130		
127.5			131.2		
127.6			130		
125.8			130		
128.7			128.8		
125.8			130		
128.3			130		
125.7	126.4	1.29	128.7	129.7	.61
130			130		
130			135.5*		
131.6			134		
130			130		
128.8			132		
130			130		
130			128.1		
128.1			128.1		
128.3			127		
132.2	129.9	.9	131.5	130.6	2.1

TABLE V.

Subject P.

High Tone.	Av.	M. V.	Low Tone.	Av.	M. V.
262.7			125.5*		
262.8			129.8		
265			131.5		
261.6			135		
260*	264.4	1.6	130.9	130.5	2.5
260			133.6		
269.9			131.6		
264.5			136.5		
262.5			131		
264.7	264.3	2.4	135.1	133.3	1.8
265.5			132.4		
270			135		
270			135.2		
262.1			130		
265	266.5	2.7	133.6	133.2	1.6
262.6			132		
267.2			135.5		
266.5			131.3		
270*			133.8		
262.5	265.7	2.5	135.8*	133.6	1.6

Medium Tone.

	Av.	M. V.		Av.	M. V.
202.5*			225		
210			223.1		
222.5			227.5		
223.7			225		
222.5	216.2	8.0	227.5	225.6	1.5
225			224.6		
222			228.6		
225			225*		
223.3			227.5		
225	224.0	1.3	225	226.2	1.5

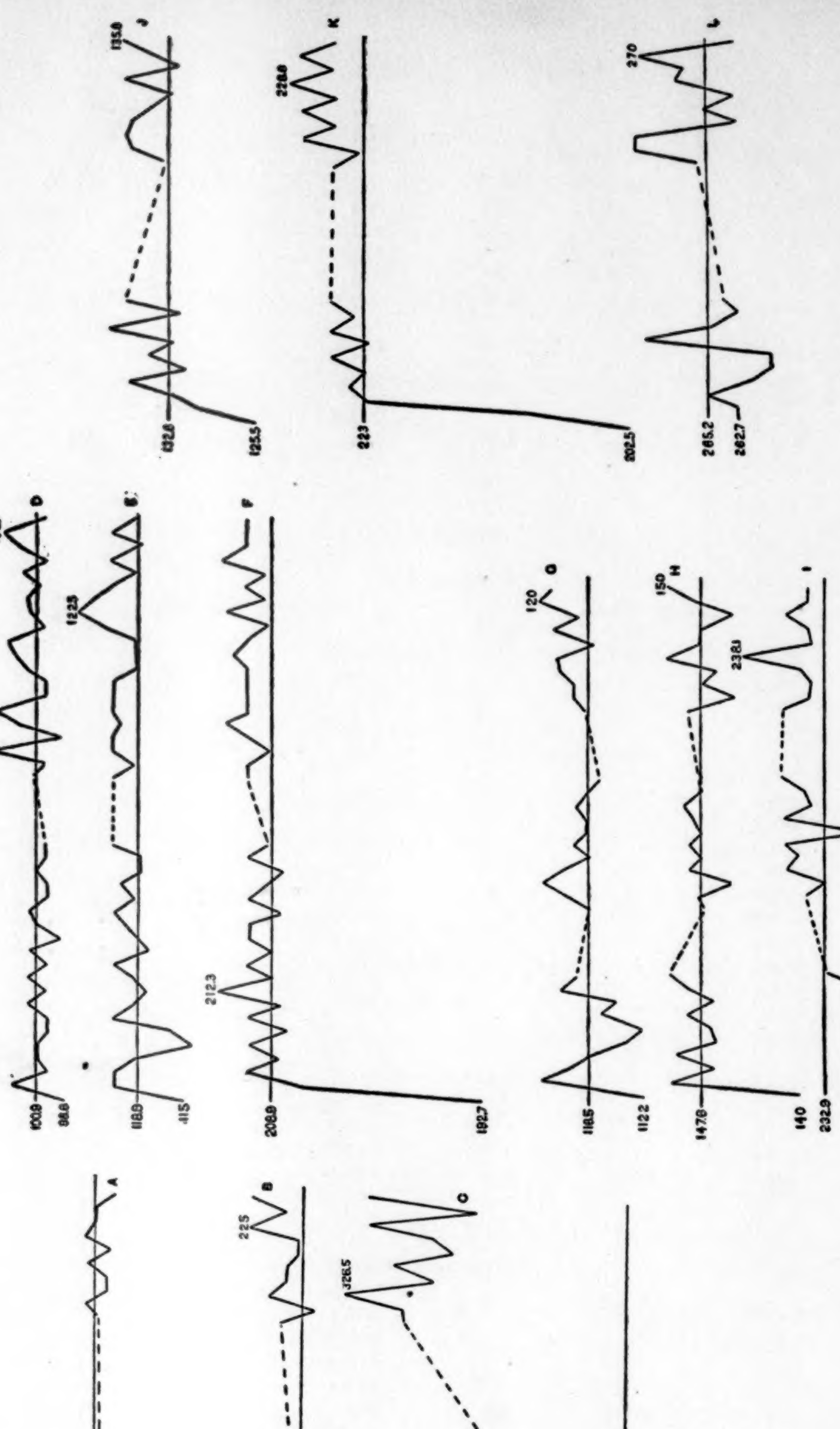
TABLE VI.

SUBJECT Fs.

	High Tone. Av.	M. V.		*Low Tone.* Av.	M. V.
290*			101.5*		
310			105.9		
311.2			110		
310			114.1*		
305	304.4	6.6	115	109.3	4.4
310			110		
312.5			111.2		
314.6			112.3		
310			109.7		
315.2	312.4	1.9	111.2	110.8	0.8
322.1			111.5		
322.4			112.5		
326.5*			110.9		
320			111		
323.3	322.8	1.6	112.1	111.6	0.5
318.6			110.6		
320			112.5		
325			111.7		
316.6			111.7		
325	321.0	3.1	110	111.3	0.8

Medium Tone.

207*			222.6		
216.2			220.5		
223.3			223.3		
223.3			222.3		
222	218.3	5.9	222	222.0	0.7
220.5			221.3		
220			221.1		
222			225*		
220			222.1		
221.7	220.8	0.9	224.6	222.8	1.5



114.8
110.7
101.5
A
225
220.9
207
B
326.5
315
280
C
100.9
98.6
101.9
D
118.9
115
122.5
E
212.3
208.9
192.7
F
120
118.5
112.2
G
150
147.8
140
H
238.1
232.9
230
I
133.8
132.8
125.5
J
228.8
223
202.5
K
270
265.2
262.7
L

FIG. 75.

The most striking feature of the results is, of course, the lack of uniformity of pitch in each of the tones. The lack of uniformity shows itself in three ways: (1) In a marked period of disturbance at the beginning of the tone shown in a high mean variation. This disturbance is not uniformly present but, taken in connection with results to be reported later, it may be considered as quite typical. It usually occurs within a period of three tenths second from the beginning of the tone, and is characterized usually, though not invariably, by a marked rise in pitch during the second tenth of a second over that of the first period of the same length. In only one case out of the twenty-one recorded above is there an actual decrease in pitch at this point in the tone. This occurs in Cg.'s high tone (Table IV.). One or two other cases occur in which the rise of pitch is not marked, but in the great majority of cases there is a rise in pitch quite extraordinary as compared with differences in pitch elsewhere in the tone. This rise is so general a feature of the beginning of a tone, as shown by these and numerous other records made in connection with this investigation, as to warrant the statement that it is a universal tendency.

Out of the thirty-five records not reported in full, taken from three different subjects for the express purpose of testing this point, there was only one in which there was a lowering in pitch during the second tenth of a second. In this case the difference was slight, while in the majority of the cases of the usual type there is a very marked difference.

Plainly, the system of measurement by tenths of a second may result in some cases in covering up the fact of such a rise, since there follows after the rise a lowering of the pitch usually appearing in the third tenth of a second. If the lowering occurs somewhat sooner than the third tenth of a second, it will then be included in the measurement of the second and disguise the fact of the real rise.

The following table gives the results of the measurement of the beginnings of eight tones in periods of twentieths of seconds, the time line having been obtained from a vibrating 100 V.D. fork.

TABLE VII.

SUBJECT FN.

I.	III.	V.	VII.
245	152	300	95.6
273.2	162.2	303.8	102.6
301.1	174.6	310	106.6
300	160	310	105.2
281.7		310	
		307.5	
II.	**IV.**	**VI.**	**VIII.**
140	150.6	290	109.6
154.8	171.6	300	114.2
160	183.2	300	116.9
168.5	188.2	300	112.4
166.2	186.6	297.4	

It will be seen that the point at which the pitch begins to decrease may be within the second tenth of a second, as shown in the first and last of these tones. Had the latter, for instance, been measured by tenths instead of twentieths of seconds, the difference between the pitch of the beginning of the tone and the highest pitch would have been 2.7 as against 7.3 vibrations. In view of the well-known fact that, in the training of the voice a correct attack is one of the most difficult things to cultivate, these results have been extended to make the matter as clear as possible. The fact that the rise in pitch appears even in the singing of subjects who have had special training seems to indicate that it is due to a physiological factor not under the control of the singer.

In the second place there is noticeable in the tables a tendency to make the latter part of the tone higher than the first. While this tendency is not universal, it seems to be typical in the case of the subjects that have been examined. Ce.'s low tone and Cg.'s high tone are the only exceptions. The tendency to sharp the latter portion of the tone is indicated in the curves of Fig. 75, page 256, and in the relative position of the starred figures in Tables I.–VI.

The third characteristic is the lack of uniformity in the record of the succeeding periods of each of the tones. It is a rare occurrence for the number of vibrations to be the same in any two successive periods of one hundred sigmas, though the pitch of some of the periods at the beginning of Fn.'s high

tone, Table II., p. 250, are quite remarkable for their uniformity as compared with the other records of this series, as well as those which were obtained later. This marked irregularity in the maintaining of any tone is apparent in all the records examined. The time involved in the changes of pitch is so short and the changes themselves so small as to preclude the probability of their being reactions of a fully conscious kind.

Involuntary movements of a similar kind are found to be present in other forms of motor adjustment under analogous conditions. The eye, for instance, in fixating a point, does not do so exactly, but oscillates more or less in various directions about the point.[1] So, too, in the state of muscular tension preparatory to the signal for reacting in reaction-time experiments, the subject's hand does not maintain exactly the same tension, but moves upward and downward in a somewhat rhythmical fashion.[2]

The rhythm of muscular response in the case of voluntary and reflex contraction has been made the subject of much study. It has been variously stated by investigators that the rate of such rhythm of response is from 8 to 20 per second. The tables show that in the case of the muscles used in control of the pitch of the human voice the rhythm is by no means a regular one. In all of the records the measurements were made by tenths of seconds, but while some of them show a somewhat marked rhythm for this period, for the most part the changes in pitch from higher to lower or lower to higher occur at irregular intervals.

Of course, this might be due to the fact that the period of the rhythm and that of the time line do not exactly correspond. In order to test this point somewhat more carefully, a number of records were taken, in which the time line was obtained from a vibrating fork of 100 V.D. frequency. In this way a few measurements were made of each succeeding 10 sigmas of certain tones. The results for three different tones given in the

[1] Cloyd N. McAllister, 'The fixation of points in the visual field,' *Yale Psychological Studies,* New Series, Psychological Review Monograph Suppiement, Vol. I., No. 1, p. 17.

[2] Judd, McAllister and Steele, 'Analyses of Reaction Movements,' *Yale Psychological Studies,* New Series, Psych. Rev. Mon. Sup Vol. I., No. 1, p. 141.

number of vibrations occurring during one hundredth of a second are as follows:

I. 1.76, 1.58, 1.76, 1.64, 1.58, 1.61, 1.62, 1.68, 1.75, 1.64, 1.68.
II. 3, 3.17, 3, 3, 3.25, 3.12, 3.12, 3, 3.06, 3, 3, 3, 3.18.
III. 2.50, 2.33, 2.22, 2.28, 2.50, 2.42, 2, 2.28, 2.14, 2.42, 2.28, 2.42, 2.25, 2.37, 2.12, 2.37, 2.37.

An examination of these figures shows that it is only in a very rough sense that the oscillation period throughout the course of the tone can be said to be rhythmical. The fact that these oscillations occur in the singing of the more trained subjects exactly as in the records of the others would seem to indicate that they are not to any great extent under conscious control.

Series II. Maintaining Tones With Short Periods of Interruption.

The second series of experiments consisted in the singing of tones as in the first series, except that each tone was interrupted by short intervals, during which the singing ceased. The object of the experiments was to see how uniformly the subjects would maintain a tone under such conditions. The average interval was three-tenths of a second and is indicated by a double horizontal line in Tables VIII. to XI. which follow. The results really represent tones of very short duration separated by short intervals. They, therefore, should be expected to be similar in character to the beginnings of tones of the earlier series. That the beginning of a tone is a period of adjustment, in which more or less irregularity of pitch occurs is here even more apparent than before. In this series, as well as the first, the introspective records generally indicate the subject's confidence in having sung the tones uniformly.

TABLE VIII.

Subject J.

Medium Tone.		*Low Tone.*	
165	148.8	103.1	121.7
169.8	162.5	122	129.1
171.5	170	127.3	130
173.3	177.2	130	131.3
172.6	172.5	127.2	130
169.5	144	118.2	120
169.3	165	125	128.1
168.5	164.8	126.3	128.3
171.5	170	128.5	129.7
173.5	168.7	130	130
161.2		120	
170		128.5	
170		129	
170		131.5	
170.9		130	

High Tone.

235	230	230	240	220
235	230.8	240	240	234.5
238	230	233.1	235	235
235	231	237.8	235	234.5
235.7	235	235	235	240

TABLE IX.

Subject Fn.

Medium Tone.		*High Tone.*	
133.8	140	188	192.3
143.8	145	198	200
140	143.1	200	200
140	143.1	204.6	200
142	143.7	206.2	204.3
135	140	201.1	200
141.8	143.3	203.1	204.8
140	140	205.5	203.3
141.1	143.3	210	204.1
141.1	143.7	210	208.2
139		192.2	
145		200	
143.5		200	
141.9		203.9	
140		202.1	

Low Tone.

105.6	101	102.8	98.2	102.8
108.1	102.1	103.3	101.9	104.2
104.2	101.7	102.6	102.5	104.4
104	101.7	103.3	103.7	105.7
103.5	103.2	103.4	104.2	104.4

TABLE X.

SUBJECT CE.

High Tone.		*Medium Tone.*	
121	122.2	120	113.3
127.6	135.2	123	125
133.5	140	124.2	124.7
134.7	140.5	124.4	125.6
135.5	139.5	124.2	125.5
122.2	130	123.5	118.1
124.4	133.8	130	124.6
135	140	125	125.4
134.1	141.5	126.6	125.8
135.8	140	124.4	124.2
125		112.9	
135.2		120	
137.5		120	
137		126.6	
136		127.1	

Low Tone.

77.4	75	74.6	77.8	80
80	74.1	74.4	80	75
78.5	77	72.1	78.9	77.5
77.5	80	77.3	80	80
79.2	79.3	78	78.9	78.8

TABLE XI.

High Tone.

224.2	232	230	230
230	235	233.3	234.2[1]
230		230	

Medium Tone.		*Low Tone.*	
174.6	183	160	157.7
190	193.3	170	166.4
190	193.3	170.8	170
190	194.2	170	166.8
		170.5	167.5
185	174.6	169.4	168.2
191.8	186.4	170	170
190	188.7	170	166.3
190	190	172.1	170
		173.3	171.4
183	180	154.2	
193.3	193	170	
193.3	195	171	
194.2	195	170	
	194.5	170	
		167.8	

[1] Record incomplete.

SERIES III. IMITATING TONES FROM ORGAN PIPES.

After these preliminary tests of a subject's ability to maintain a tone chosen at random, and to reproduce a tone after short intervals, a long series of experiments was made for the purpose of discovering the ability of one of the subjects (Fn.) to imitate the tones of organ pipes, varying in pitch from 93.7 to 302.8 vibrations per second.

These experiments were carried out in the following manner. When the subject was ready, one of the keys (*E*), Fig. 5, was pressed down, allowing the pipe, which was to be imitated, to sound for about five seconds. Immediately after the pipe had ceased sounding the reactor sang a tone which was designed to be of the same pitch as that of the pipe. After singing one tone in this way, he wrote upon a slip of paper provided for the purpose his impression concerning the exactness of the sung tone and any other features of the performance revealed by introspection.

In these experiments three sets of results were obtained. The first set, Table XII., was obtained from giving the tones from the pipes in a particular order, viz.: beginning at D (144.2 vibrations per sec.) and proceeding to D# (152.4 vibrations per sec.), and so on by regular intervals of half a tone to D#; thence beginning at C (135.6 vib. per sec.) and proceeding down the scale in a similar manner to G (93.7 vib. per sec.).

In the second set, Table XIII., no particular order was followed, but the experimenter passed from one part of the key-board to another, the effort being made to prevent any expectation on the part of the subject of the direction of the pitch of the tone, as compared with that just previously given.

The last set of results, Table XIV., was obtained in the same manner as those just mentioned except that, in the latter case, the organ pipe which was being imitated was kept sounding while the subject was singing.

The figures given in these tables represent the first and last half seconds of the tone only. Other parts of the tones are omitted for the sake of economy of space. The number of

vibrations per second of the standard tone produced by the pipe is given at the top of each column, and also the letter representing that tone in the usual notation. A space between the figures indicates that the figures above the space belong to the first part of the tone, while those below the space belong to the last part of the tone.

TABLE XII.

Standard Tones Given Consecutively.

Subject Fn.

G — 93.7.	G♯ — 100.	A — 107.1.	A♯ — 112.1.	B — 120.	C — 126.6.
101.2	96	108.7	112.7	122.3	132
110	108.6	110	118.7	120	133.7
104	110	110	120	118.2	132
104	110	111.2	121	120	131.1
106	113.3	112	120	122.5	130
103.5	115	112.1	115.7	121	131.1
101.3	113.3	110	116.6	121.5	132.9
105	115	110.5	118.1	120	132.5
107.1	114.6	110	118.1	121.5	130
110	113.3	108.7	115.8		130

C♯ — 135.6.	D — 144.2.	D♯ — 152.4.	E — 160.	F — 170.	F♯ — 178.1.
162.5	137.5	150	144.1	148.5	173.3
145	145	152.8	160	170	180
138.5	145	155.7	160	168.5	180
140	146.6	152	160	170	180
138.5	144.8	153.1	161.9	170	180
140	150	155	163.1	172.8	182.5
139.1	145	154	162.8	172.3	182.8
140	147.5	152.6	161.7	172.3	183.1
140	146.6	155	160.8	172.3	180.5
140	147	157.3	163.3	172.3	182.5

G — 187.	G♯ — 200.	A — 214.	A♯ — 225.	B — 240.	C — 255.4.
190	205	195	227.5	235	255
192.7	210	210	242.5	247.5	256.2
191.4	210	215	232.5	247.5	260
191.4	207.5	215	232.5	250	265
193.5	207.5	215	232.5	248.5	265
195.4	206.4	223.3	240	245	260
196.6	207.5	222.8	232.5	245	260
196.3	208.3	225	232.5	245	261.4
197	210	220	235	247.5	260
198.1	208.1	222.8	235	245	260

C♯ — 271.8.	D — 286.4.	D♯ — 302.8.
260	270	247.5
272.5	280	275
280	285	297.5
277.5	285	310
278.7	287.5	310
275	285	310
275	289	310
277.5	286.5	305
275	287.5	310
277.9	285	305

TABLE XIII.

Standard Tones not Given in Order.

Subject Fn.

G — 93.7.[1]	G# — 100.	A — 107.1.	A# — 112.1.	B — 120.	C — 126.6.
	101.3	123.3	118.5	123.5	121.6
	102.6	115	120	124.5	123.1
	101.6	115	120	122.9	130
	101.6	112.1	121.6	123.4	132.3
	103.3	113.3	122	124.5	130
95.8	104	114.1	124.8	122.5	135
96.2	104.2	113.1	121	122.6	134.6
95	102.1	114.1	121	125.3	131
95	105.2	112.3	125	120	132.2
98.7	102.3	112.3	124.3	120	131.5

C# — 135.6.	D — 144.2.	D# — 152.4.	E — 160.	F — 170.	F# — 178.1.
158	155.8	155	167.5	167.5	187.2
160	156.8	160	167.5	177.2	190
140	150	155	170	177.2	183.3
135.3	152	154	168.3	175.4	183.3
135.6	150	154	165	177.2	184.2
137.7	150	153.5	164	175	186.7
133.3	150	153.5	163	175	188.5
136.5	150	153.5	165	175	184.8
136.1	150	154.6	165	175	182.3
135.9	150	151.4	164.2	178.7	184.5

G — 187.	G# — 200.	A — 214.	A# — 225.	B — 240.	C — 255.4.
190	195	215	250	225	220
200	205	217.5	247.5	240	252.2
199.2	202.5	220	237.5	232.5	250
197.5	202.5	218	227.5	240	255
195	207.5	220	222.5	240	255
198.5	205	220	227.5	245	252.3
197.5	210	220	227.5	242.5	252.3
195.3	207.5	222.5	222.5	240	252.3
197.1	207.5	220	227.5	240	255
198.7	207.5	222.5		241.9	252.3

C# — 271.8.	D — 286.4.	D# — 302.8.
232.5	280	242.5
255	282.8	277.5
262.5	282.8	295
271.2	287.1	305
270	287.1	307.5
272.5	286.7	305
274.5	283.3	310
272.5	284.4	315
273.7	283.4	310
273.3	286.6	305

[1] Record illegible.

TABLE XIV.

GIVEN IRREGULARLY WITH PIPES SOUNDING.

G — 93.7.	G# — 100.	A — 107.1.	A# — 112.1.	B — 120.	C — 126.6.
104.7	102.8	109.3	114.4	122.1	130
101.2	95.2	110	115.7	121.6	132.8
101	100	109.3	116.8	120.5	130
101.9	100	111	118.2	120	130.9
100	100	111.8	118.3	118.9	133.1
97.5	103.3	110.9	116.9	124.8	133.3
97.1	101	110	116.7	122.6	133.1
100	104	110.9	117.5	122.5	133.2
99.5	102	110	117.4	122.5	131.6
98.5	104	110	116.5	121.5	130

C# — 135.6.	D — 144.2.	D# — 152.4.	E — 160.	F — 170.	F# — 178.1.
133.5	130	150	178.5	172.5	171.4
143.3	139	152.5	180	175	179.5
137.7	144	153.2	168.2	175.3	179.5
133.6	145.2	150.5	162.6	172.1	180
133.3	147.3	150.9	164.5	173.1	181.5
134.5		153.4	160	174.2	183.1
134.5		152.7	161.5	171.1	181.6
135.4		151.3	161.5	173.3	180
134.2		150.8	161	173.3	182.5
135		150.5	165	175.8	180

G — 187.	G# — 200.	A — 214.	A# — 225.	B — 240.	C — 255.4.
270	222.5	216.2	249.1	154.2	196.5
258.7	230	212.5	240	199.2	212.5
232.5	212.5	212.5	230	217.5	245
220	206.8	216.7	232.5	242.5	266.2
210	205	216.2	230	252.5	274
205.2	205	220	230	240	270
205	205	217.5	227.7	241.5	272
205	205	220	227.1	242.5	270
200	202.5	220	227.1	242.5	272.3
204	204.4	220	225	242.8	273.8

C# — 271.8.	D — 286.4.	D# — 302.8.
271	260	285
287.2	280	292.5
271.5	285	307
287.2	285	309
271.5	286	308
272	286.2	305.5
272	288.3	303.3
272	283.8	303.3
272.5	288.3	302.2
270	284.4	304.4

The above series of tables present complete results for twenty-one tones from one subject (Fn.). In the case of the other subjects, a less comprehensive series of tests was made, the number of tones for each person having been reduced to three. One of these three tones was of high pitch, one of low pitch, and one of medium pitch.

The medium pitch given for imitation was in each case E = 160 vibrations per second, but the high and low pitches varied with the natural range of the singer. J. and Ce. sang each of the three tones both with and without the simultaneous sounding of the standard tone; Cg. and P. gave records of the three tones under the latter conditions only, that is, after the pipe had ceased sounding. The tables presenting the results for these four subjects follow (Tables XV.–XVIII).

TABLE XV.

SUBJECT J.

After Pipes had Ceased Sounding.

C — 255.4.	E — 160.	C — 126.6.
245	164.7	131.7
264.2	172.5	132.3
260	172.9	131.3
264.5	176	133.5
265	172.5	132.7
258.5	181	135.1
255.8	181.1	135
257.6	181.8	137.6
261.5	179.5	132.6
261.5	182.5	131.6

With Pipes Sounding.

C — 255.4.	E — 160.	C — 126.6.
240	215	118.7
260	217.5	120
253.1	216.2	118.8
250	215	123.1
250	217.5	123
257.5	218	128.6
260	217.5	127.7
257.5	217.5	130
260	217.5	128.9
258.7	217.5	127.5

TABLE XVI.

SUBJECT CE.

After Pipes had Ceased Sounding.

D — 286.2.	E — 160.	A — 107.1.
280	159.2	97.7
285	167.5	110
290	160	107.3
290	162.5	105
288.5	162.5	105.6
290	160	106.1
293.6	161.2	107.8
293.3	160	106.5
290	160	107.2
293.8	164.1	107.5

With Pipes Sounding.

D — 286.2.	E — 160.	A — 107.1.
282.1	158.5	105.6
292.5	160	106.4
285.3	159.5	106.6
287.8	161.7	106
290	160	105
288.5	159.5	107
290	160	106.3
291.3	160	107
291.3	159.5	107
291.3	159.5	105

TABLE XVII.

SUBJECT Cg.

After Pipes had Ceased Sounding.

C♯ — 271.8.	E — 160.	C — 126.6
271.8	160	135.2
275.6	162.1	135.2
271.2	164.4	136.4
278.8	164	134.6
273.6	163.2	132.9
275.2	163.7	136.3
277.5	163.3	134
274	165.6	134
276.4		137.5
276.4		137.2

TABLE XVIII.

SUBJECT P.

After Pipes had Ceased Sounding.

D♯ — 302.6.	E — 160.	A♯ — 112.1.
232.6	146.6	104.2
250	160	105
282.5	162.8	112.9
300	170	112.7
306.6	161	115
304	162.5	117.5
308.5	160	120
302	162.2	115
301.5	165	120
301.1		114.6

The results presented in these tables are similar in certain general characteristics to those of the earlier series made without the use of pipes. Of the eighty-one tones, figures for which are given, only ten show a decrease in the pitch during the second tenth of a second. Of these ten there are three in which the difference in pitch is less than three vibrations, an amount which is quite insignificant as compared with the usual

large amount of increase in pitch during the same period. In the remaining seven cases the beginning of the tone is considerably higher than the standard and the decrease in pitch during the second tenth of a second is merely a part of a general lowering of the tone to make it conform to the standard.

An interesting instance of this kind is afforded by the figures given for C—135.6, Table XII., page 264. It will be remembered that this is the point at which the change was made in the order of the standard tones. Up to this point the subject had been singing successively higher tones, until the upper limit of the experiment (D—302.8) had been reached. The experimenter then went back to the tone next lower than the tone with which the series was begun. That the expectation created by the manner of procedure, either in the form of a mental tendency or a motor adjustment, had its effect is clearly shown by the record. Instead of the beginning of the tone being considerably lower than the standard tone and the immediately following part much higher, as is usually the case, the beginning is much higher than the standard and the tone at once begins to drop in pitch, so that the larger part of the tone becomes a fair approximation of the standard. The introspective record does not show that the subject was conscious of the character of the early part of the tone. In other cases where there is a marked change of pitch in the early part of the tone there is sometimes a recognition of the fact after the singing has ended, as shown by the introspective records, but usually this is not the case.

Take, for example, the record for C—255.4 vib., Table XIV., page 266, in the last of the series under consideration, where the pipe was sounding while the singing was going on. The subject noted that the beginning of the tone was much too low, and ascribed the trouble to a difficulty he felt in motor control. He failed to note, however, that in overcoming the flattening at the beginning, he went too far in the other direction, making the tone as a whole higher than the standard, and to a degree which is quite uncommon in other cases where he sang tones of that range.

As was to be expected, the introspective records show that

the subject is more confident in his judgments as to the success of his singing in the experiments where the pipe was kept sounding. An important point which is brought out by the introspection of Fn. in connection with the later series, relates to the direction of the attention during the singing. Sometimes the attention was more fully centered upon the auditory stimulus from the sounding pipe, sometimes upon the singing of the tone. No different results were noted, however, corresponding to these different directions of the attention.

Another point demanding fuller study is the effect which the singing of a tone has upon a following tone. An instance of this kind is the one mentioned above, where the effect of singing a series of progressively higher tones led to a failure in adjustment at the beginning, when a lower tone was given as the standard. The following table, Table XIX., gives some results which are interesting in this connection. These results were obtained from the measurements of some records previous to the perfecting of the apparatus for measurement and, therefore, may not be as accurate as the other results.

The subject, Mr. W. M. Steele, was asked to sing two tones, A—219.5 vib., and C—265 vib., in succession, with a short pause between. This was done three times. He was then asked to sing the tones in the reverse order three times. The standard tones were given by means of a pitch pipe in the order they were to be sung.

The table follows:

TABLE XIX.

A — 219.5	224	217	222	...	220	222	222
C — 265	277	270	270				
A — 219.5	225	220	220	...	227	228	223
C — 265	268	269	265				
A — 219.5	200	220	216				
C — 265	225	221	255	280	269	270	
C — 265	265	265	269	...	270	270	261
A — 219.5	201	209	200	209	210	210	210
C — 265	280	270	266	...	270	270	260
A — 219.5	218	212	215				
C — 265	278	266	268	...	271	280	270
A — 219.5	200	210	212				

It will be seen that where A precedes C, it is always to a greater or less degree higher in pitch than the standard. On the other hand, when A follows C it is invariably lower than the standard.

Other instances of the effect of a tone upon an immediately succeeding tone might be taken from some of the results when the subjects had little or no 'ear for music.'

One subject, Dr. C. M. McAllister, who had enough musical development to sing an air with others, and who could discriminate different pitches fairly well, was asked to sing any tone he wished, taken at random. The tone sung averaged 221 vib. per sec. He was then given a standard tone of 193 vib. per sec., and asked to imitate it. He responded with a tone of 231 vib. per sec. Holding to 193 vib. per sec. as the standard, he was asked to sing it, and other tones were used as distractions. Three tones sung under such conditions averaged 230, 231 and 222 vib. per sec., respectively. To what extent the failure to sing a tone correctly under such conditions is due to lack of the powers of auditory discrimination and to what extent it is due to lack of motor control, is a question which might be investigated with profit.

Another subject, Mr. Browning, when given a tone from a pipe to imitate, would fairly approximate the standard. Succeeding tones, however, were all sung at practically the same pitch if they were anywhere within the same range. It was only by changing the standard to one much higher or lower than the first given that any change in the pitch of the sung tone could be obtained.

In order to show how nearly the tones were approximated in each case the figures of Tables XII. to XIV. have been averaged (Table XX., page 272) and the error computed as a percentage of the number of vibrations of the standard tone. Since, however, the beginning of the tone is, as has been seen, a period of adjustment, the average of the first five measurements was not considered in these computations. The average tone is more adequately represented by the average of the remaining part of the tone, since the first average in the table represents but a comparatively small portion of the tone.

Where the average tone is higher than the standard, this fact is represented by the positive sign, and where it is lower the negative sign is used to indicate that fact. Table XX. gives the per cent. of error for each of the tones as sung under the conditions already described.

TABLE XX.

PERCENTAGE OF ERROR.

Subject Fn.

Tone.	No. Vib.	Standard Given in Order of Pitch.	Standard given in Irregular order.	Pipe Sounding.	Average for each Tone.
G	93.7	+ 11.9	+ 3.65	+ 5.0	6.8
G♯	100	+ 13.6	+ 3.6	+ 1.6	6.2
A	107.1	+ 3.5	+ 4.8	+ 3.4	3.9
A♯	112.1	+ 5.3	+ 8.3	+ 5.6	6.0
B	120	+ 0.8	+ 2.1	+ 1.6	1.5
C	126.6	+ 3.4	+ 3.3	+ 4.4	3.7
C♯	135.6	+ 3.1	+ 0.2	— 0.3	1.2
D	144.2	+ 1.7	+ 3.7	+ 0.3	1.9
D♯	152.4	+ 0.5	+ 1.4	— 0.3	0.7
E	160	+ 3.3	+ 2.8	+ 1.4	2.5
F	170	+ 1.4	+ 2.9	+ 2.0	2.1
F♯	178.1	+ 1.8	+ 4.0	+ 2.6	2.8
G	187	+ 4.8	+ 4.9	+ 9.0	6.2
G♯	200	+ 3.3	+ 4.0	+ 2.8	3.3
A	214	+ 4.3	+ 2.7	+ 2.3	3.1
A♯	225	+ 3.8	+ 0.7	+ 1.1	1.8
B	240	+ 2.1	+ 0.04	+ 0.8	0.9
C	255.4	+ 1.6	— 0.5	+ 6.3	2.8
C♯	271.8	+ 1.6	+ 0.2	— 0.4	0.7
D	286.4	+ 0.4	— 0.2	— 0.5	0.3
D♯	302.8	+ 1.7	+ 1.4	+ 0.5	1.2

Subject J.

Tone.	No. Vib.	After Pipe.	Pipe Sounding.
E	160	+ 13.0	+ 3.5
C	225.4	+ 1.2	+ 0.5
C	126.6	+ 6.2	+ 0.3

Subject Fs.

Tone.	No. Vib.	After Pipe.	Pipe Sounding.
E	160	+ 0.2	
D	302.8	— (100 + 0.2)	
A	107.1	+ 1.9	

Subject Ce.

Tone.	No. Vib.	After Pipe.	Pipe Sounding.
E	160	+ 0.6	+ 0.3
A	112.1	— 0.8	— 0.3
D	286.2	+ 1.8	+ 1.3

Subject Cg.

Tone.	No. Vib.	After Pipe.	Pipe Sounding.
E	610	+ 1.3	
C	126.6	+ 6.2	
C	271.8	+ 1.8	

Subject P.

Tone.	No. Vib.	After Pipe.	Pipe Sounding.
A	112.1	+ 4.7	
E	160	+ 1.0	
D	302.8	+ 0.7	

Subject G.

Tone.	No. Vib.	After Pipe.	Pipe Sounding.
E	160	+ 1.0	
B	240	+ 1.2	

It will be seen that the per cent. of error varies all the way from 0.04 per cent. to 13.6 per cent. Klünder[1] found an error of only a small fraction over 3 per cent. to be the maximum in the subjects he examined. In making his computation, however, he rejected all those records which showed unusually large errors. Moreover, his subjects were chosen because of their musical training and ability. It should be remembered also that the conditions of Klünder's experiment made it necessary that the record from the voice and organ pipe should be taken simultaneously. This probably aids in exactness, though the figures of Table XX. are not very conclusive on that point. If we except the records for G—187 vib. and C—255.4 vib., the gain in accuracy when the pipe is sounding is more marked. Both of these cases evidently come under the class of records rejected by Klünder. The introspective record shows that the subject knew of his error and it seems fair to conclude that unknown distracting conditions were present in these cases, resulting in a lack of motor control which he could no doubt correct if given another opportunity.

By far the greater error occurs in connection with the low tones. This is in accordance with the subject's own judgment as to his ability in discriminating these tones. He experienced much more difficulty and confusion in discriminating low tones in general, and felt less certainly that he had correctly imitated them. The higher tones, except in the cases just mentioned, were very closely approximated. These remarks are true, not only of Fn.'s results, but also of those of the other subjects examined except Fs.

The most marked feature presented by Table XX. is the almost universal presence of the plus sign indicating a higher tone than the standard. Fn.'s tendency is plainly to sing a tone higher than the standard which he is endeavoring to imitate. In only six cases out of the sixty-three does he sing the tone lower than it should be sung. In these six cases the amount of error is extremely small. Four of these occur in the singing of the higher tones, thus making it appear that the

[1] 'Ueber die Genauigkeit der Stimme,' *Arch. f. Anat. u. Physiol.* (Physiol. Abth.), 1879, p. 119.

natural tendency to sharp had been overcome by the difficulty of reaching these higher tones. With the other subjects examined the tendency is also general to sing the tone higher than the standard.

TABLE XXI.

	Without Pipe Sounding.		With Pipe Sounding.
	SUBJECT FN.		
1	2.3	3.0	2.9
2	3.2	2.8	1.5
3	3.2	3.9	1.7
4	2.9	2.4	1.1
5	2.1	2.5	1.5
6	2.6	4.6	2.2
7	2.5	6.1	2.1
8	2.6	0.8	1.6
9	1.9	3.0	2.1
10	3.0	1.7	3.5
11	2.3	3.4	1.5
12	1.9	3.8	3.6
13	3.3	3.1	3.7
14	2.3	3.2	2.5
15	4.0	3.9	3.2
16	4.6	4.5	4.5
17	2.3	4.2	4.7
18	3.5	3.1	2.9
19	3.7	3.6	2.4
20	4.9	3.1	3.8
21	4.0	5.0	2.7
Av.	3.0	3.1	2.4
	SUBJECT CE.		
		5.4	4.8
		2.9	1.8
		3.4	1.3
Av.		3.9	2.6
	SUBJECT J.		
		2.2	1.5
		3.6	3.3
		3.4	2.5
Av		3.1	2.4

Attention has been drawn to the fact that a difference in accuracy in favor of the tones accompanied by the sounding pipe can be noted from the above figures. There is one other way in which the accuracy of the sung tone may perhaps be affected by the actual presence of the standard tone. The tone may be more uniform from period to period during the course of the singing. The foregoing table, Table XXI., is designed

to show the comparative uniformity of the tones. The figures represent the sum of the three mean variations of each of the columns in Table XX. It also shows similar results of tones sung by Ce. and J. with and without the presence of the sounding pipe.

Twenty-seven cases in all are thus represented. In all but eight cases the mean variation is less for the tones with the pipe sounding. But there are two series without the pipe. In only three cases of the eight are the mean variations in the third column greater than both of the others. These figures indicate a slightly greater degree of uniformity for the tones accompanied by the sounding pipe.

Series IV. Effects of Distraction.

The remainder of the investigation relates to the effect of distractions in connection with the singing of tones. The procedure followed was practically the same as in the earlier series except that a distraction (usually a tone from one of the pipes) was used during the singing of the standard tone.

The standard tone which the subject tried to imitate was given as before for the same length of time. Immediately on releasing the key and thus causing the cessation of the tone from the pipe which was used for the standard, a second tone was sounded for the purpose of distracting the subject.

It was planned to begin the distracting tone in this way at the same time or a little before the sung tone had begun, and to continue it while the latter was being sung. Sometimes designedly, and sometimes on account of the slowness of the operator in pressing the second key, the subject began to sing a little before the tone designed to distract him had set in, but in nearly every case the distracting tone had begun before the singing of the tone commenced.

The distracting tones were distributed so as to test the influence which might be made upon the singing by the simultaneous sounding of tones which were (1) harmonious or inharmonious with the standard tone; (2) of greater or less interval from the standard; and (3) higher or lower than the standard.

In a few cases the form of distraction used was a sudden loud noise caused by the stamping of the foot upon the floor at the moment when the singing was about to begin.

In the manner just described, a series of records was obtained of tones sung under different conditions of distractions. In the following tables, as in the preceding, the figures for the first half second and last half second only are given.

Whenever it was thought probable that other portions of the record might show signs of distraction, these were also read; but disturbances when they occurred almost invariably showed themselves at the beginning of the tone, or in the pitch of the tone as a whole.

Records of the singing of thirteen tones under conditions of distraction were obtained from subject Fn., and these all appear in the following tables. In the case of the other subject three tones, one of high pitch, one of low pitch, and one of medium pitch were in general used. It is not thought necessary to indicate the full series of figures from the records of these latter subjects. The percentage of error and its direction only are given in some cases where the disturbing influence is apparent throughout the whole of the record. In a few cases where no effect of distraction is apparent, that fact is indicated without the numerical statement.

The pitch of the standard tone is indicated at the top of each table, and the distracting tone is also given at the top of the column of figures indicating the results of the tone sung, when that particular distracting tone was used.

The tones are given in the order in which they are sung, but this order is not considered significant, as there was a sufficiently long interval after each experiment, to preclude the possibility of any influence lasting over from one tone to the next. The figures for the whole series of tones sung under conditions of distraction are presented in Tables XXII. to XXVIII. Tables XXV. to XXVIII. indicate the results in an abbreviated form, either by stating the fact that no distraction occurred or by giving the percentage of error and indicating its direction by the positive or negative sign.

TABLE XXII.—SUBJECT FN.

Standard F — 170.

G — 187.	D♯ — 302.8.	G — 93.7.	D♯ — 152.4	Stamp.
151.2	167.1	152.3	153.4	152.5
160	172.8	163.1	174.1	165.6
163.7	168.8	167	168.5	170
166.6	170	170	170	172.3
167.7	170	173.3	173.1	160
167.2	173.5	171.5	173.9	170
167.2	174	171.5	176.1	170
167.2	173.5	170	175.2	170
166.6	174.2	171.5	174.3	168.9
166	175	170	171.7	

Standard C — 126.6.

C♯ — 135.6.	E — 160.	C♯ — 271.8.	E — 80.
126.6	120	130	182.7
130	125	128.1	200.2
135.8	130	129.5	207.5
137.2	130	129.5	205
134.9	130	130	207.5
133.3	130	132.6	210
135.2	141.1	132.8	210
135.2	130	131.4	210
137.1	131	132.5	210
136.5	130	132.5	205

Standard B — 120.

C♯ — 135.6.	D — 144.2.	C♯ — 271.8.	D — 286.2.
114	130	115.4	122.1
120	120	115.8	124.5
110	120	119	124.5
110	120	119	123.4
110	120	120	120.6
118.8	122.2	122	124.5
116.2	121.5	122.9	124.2
120	120.9	121.3	123.5
120	121.8	122.6	122.1
118.1	125	121.2	120

Standard G♯ — 200

Stamp.	A♯ — 225.	C — 255.4.	A♯ — 112.1.	C — 126.6.
174.6	190	190	232.5	200
196.8	207.5	207.5	235	197.5
200	203.4	205	220.2	200
198.7	205	205	215	200
198.7	207.5	200.2	217.5	200
207.5	205	205	217.5	204.3
200	205	205	220	211.5
	207.5	207.5	220	206.5
	205	205	220	205
	205	205	220	205

Standard A — 107.1.

C — 126.6	Stamp.	C# — 135.6	C — 255.4.	C# — 271.8
100.8	117.6	100	114.1	115
106.7	112.4	110	112.3	115.5
114.7	110	110	111	114.6
108.5	112.5	110	112.2	113.2
108.5	112	110	112.8	112.4
107.5		108.9	112.5	112.4
108.7		110	111.2	115.2
108.7		108.5	110.8	114
108.7		110	110	114
106.2		108.1	110	113.5

Standard E — 160.

E — 80.	F — 170.	C — 126.6.	C — 255.4.
150	151.3	156	141.5
155.2	160	164	158
153.3	158	164.4	160
156	163.5	163.5	162
156	164.1	164.1	160.5
160	162.4	164.5	160.4
158.6	162.6	164	161.3
160	161.6	162.2	161.3
158.5		165	161.3
158.5		161	160

Standard C# — 135.6.

C — 126.6.	D# — 152.4.	C — 255.4.	D# — 75.5.
127.5	130	121.8	119.3
134.1	137.5	131.4	122.8
140	138.3	136.1	125
138.5	138.4	136.6	125.8
138.5	140	138.3	129
141.4	138.6	138.5	130
141.2	140	137.5	128
140	137.1	140	128.4
138.8	138.1	140	125.4
	137.1	143	127

Standard A — 214.

C — 255.4.	B — 240.	C — 126.6.	B — 120.
210	205	190	210
217.7	212.7	210	215
220	217.4	212.5	218.7
220	215	210	218.7
220	217.6	217.5	217.5
221.2	220	222.2	221.2
221.2	220	222.3	222.5
217.5	220	220	222.5
217.5	218.5	221.8	220.5
221.2	218.5	221.8	221.2

Stndard D — 144.2.

E — 160.	G — 187.	G — 93.7.	E — 80.
135.5	143	131.1	142.5
145	148.4	144	144.1
144.1	146.4	144	141
145.5	146.2	145.3	141
144.7	145	144.7	144
144.1	146.1	145.2	144.8
144.1	146.2	143.6	145
143.1	146.6	143.6	145.4
142.7	146.1	146.1	145.3
143.1	145	146.1	145.9

Standard G♯ — 100.

D♯ — 75.5.	G — 93.7.	D♯ — 152.4.	G♯ — 200.
100	102.5	107.4	105
100	102.5	105.7	105.3
104.7	102.5	104.3	104.8
102.7	104.2	104.1	105.4
103.6	105.8	103.3	105
104.9	104	105	104.3
105.1	105	105.7	103.2
106	103.9	105	103.1
105.6	105.3	104.5	105
	108.3	106.6	105

Standard D — 302.8.

D — 144.2.	D — 286.2.	B — 120.	B — 240.
171.5	293.3	265	292.4
177.5	312.5	310	304.5
175	310	305	310
177.5	310	305	310
195	312.5	305	310
301.3	312.2	310	310
299.5	310	312.5	308.7
300	310	310	310
303.5	310	307.5	310
305		308.7	310

Standard G — 187.

G♯ — 200.	C — 255.4.	G — 93.7.	C — 126.6
128.3	190	225	174.6
145	202.2	192.3	183.7
167	196.1	181.5	191.7
181.7	192.5	187.5	190
192.5	195	192.2	193.6
197.5	197.1	193.3	195
195.6	195	195	195
195.6	195	195	194
195.6	197.2	193.5	193.3
194.3	192.5	190	194.2

Standard A♯ — 112.1.

C♯ — 271.8.	E — 160.	A♯ — 225.	F — 85.
131.3	111.6	107.5	
137.5	120	118.2	111.2
122.4	115.6	118.2	112
115	115.6	120	113.3
113.1	118.3	118.2	112.1
117.5	117.5	118.4	115.8
117.5	118.5	118.4	115
117.5	118.1	116.1	115
116.2	117.5	118.4	114.8
115.4		118.2	113.3

TABLE XXIII.—Subject J.

Standard C — 126.6.

High sung tone.	C — 135.6.	C — 271.8.	A — 107.1.
192.3	137.5	142.5	141
174.3	137.5	155.3	159.1
175.3	139.1	160	173.6
182.2	138.3	167.4	184.3
187.1	138.7	167.8	194.1
187.3	138.5	170	156.5
187.5	136.6	168.6	156.1
185.5	136.6	166.3	157.7
185	137.5	167.6	154
	136.6	170	155.3

Standard C — 255.4.

C♯ — 271.8.	D♯ — 302.8.	D♯ — 152.4.	A — 112.1.
242.2	232.7	257.4	250
251.6	250	280	250
252.4	260	285	247.8
256.5	269.1	290	250
265	272.4	284.2	249.3
275	310	304.7	
275	310	309.4	
278.7	315	310	
275	310	310	
275	314.7	309.1	

Standard E — 160.

F — 170.	C — 255.4.	C — 126.6.	F — 85.
227.5	184	175.5	204
227.5	190	181	205
232.5	196.1	185.8	204
233.7	200	188.1	208.7
232.5	203.3	186.6	205
240	198	188.7	205
240	197.7	190	205
236.6	200	190	207.5
235	198.6	190	205
242.5	200	192.5	207

TABLE XXIV.—SUBJECT CE.

Standard E — 160.

Stamp. No. dis.	D♯ — 302.8 No. dis.
F — 85 No. dis.	D♯ — 152.4 No. dis.
C♯ — 135.6	C♯ — 135.6 No. dis.
128.5 127.1 126.8 128 128.1	D♯ — 152.4 No. dis. D♯ — 75.5 No. dis.
126.3 128 128.3 126.6 123.3	A♯ — 112.1 No. dis.

Standard D — 286.4.

D♯ — 302.8.	Stamp.	G — 93.7.	G — 187.
292.5	272.7	257.5	272.2
305	315.6	280	283.3
320	307.5	302.8	291.6
316.6	295.8	289.5	296.1
305	292.5	292.1	290
290	292.3	291.2	290
287	295	290	288.8
292.5	282.3	291.3	291.2
283.3	288.7	294	290
287.5	287.5	291.7	290

TABLE XXV.—SUBJECT CG.

Standard E — 160.

G — 93.7 No. dis.	C♯ — 271.8 No. dis.
F♯ — 178.1 No. dis.	D♯ — 152.4 No. dis.

Standard C — 271.8.

D — 286.4 + 7.7	D — 144.2 — 4.1
C♯ — 135.6 No. dis.	C — 126.6 No. dis.

TABLE XXVI.—SUBJECT G.

Standard E — 160.

D♯ — 302.8 — 12.1	C — 126.6 — 21.7
F — 170 + 7.6	D♯ — 152.4 + 16.3

Standard B — 240.

C — 255.4 No. dis.	D♯ — 302.8 No. dis.
C — 126.6 No. dis.	

TABLE XXVII.—Subject P.

Standard E — 160.

F — 120 + 37.1	D♯ — 302.8 + 33.7
C — 271.8 + 37.9	A♯ — 112.1 + 35.2
F — 170 + 9.7	

Standard D♯ — 302.8.

D♯ — 152.4 No. dis.	E — 286.4 No. dis.

Standard A♯ — 112.1.

C — 126.6 + 15.2	A — 214 + 20.2

TABLE XXVIII.—Subject Fs.

Standard D♯ — 302.8.

D — (100 + 1.1)	C No. dis.	F No. dis

Standard — 107.1.

A♯
— 2.9

Standard E — 160.

F — 170
No. dis.

From an examination of the figures in Tables XXII. to XXVIII., it appears that the distracting tones made an effect upon the pitch of a little less than forty per cent. of cases. Out of one hundred and ten cases recorded, forty-four show clear evidence of the effect of distraction. These are distributed as follows: Subj. Fn., fifteen cases out of fifty-five; Subj. J., thirteen cases out of fourteen; Subj. Ce., two cases out of eight; Subj. G., four cases out of seven; Subj. P., seven cases out of nine; Subj. Fs., one case out of five. Expressed in per cent. the following table gives the relative sensitiveness to distraction:

TABLE XXIX.

Subj.	Per Cent. of Cases in which distraction Occurs.
Fn.	27.2
J.	87.1
Ce.	16.6
Cg.	25
G.	57.1
P.	77.7
Fs.	20

Thus it is seen that the greatest effect of distractions seems to have occurred with J., who is the least trained of all the subjects in musical ability. On the other hand, P., who has had more training in singing than any of the other subjects except Fs., seems only a little less susceptible to distractions than J. Fn. and Cg., who may be roughly classed together with regard to their musical training, are affected by distractions in about the same proportion of cases. G., who belongs approximately to the same class, is disturbed in a much greater proportion of cases. Fs., who has had the advantage of a large amount of training, shows the least disturbance from distraction, with the exception of Ce.

While, therefore, there is a general correspondence between the amount of distraction and the musical training, other influences are apparently present. Since the number of experiments in the case of each individual is not the same, the general tendency may be emphasized even though it is not borne out in every detail. It is interesting to note that Fs., the most trained subject, was the only one to mistake one octave for another. (See Table XXVIII., page 282; also Table XXX., page 285.)

It will now be necessary to state in what ways the presence of the distraction manifests itself. In general it may be said that if the distracting tone has a disturbing effect, the effect is shown in one of two ways. The distracting tone may, in the first place, cause the subject to sing a tone which is much higher or much lower than the standard throughout the whole period. Such an effect is shown in the tables which follow Table XXX., page 285, in a large plus or minus percentage of error. In the second place, the beginning only of the tone may be affected by the distraction while the greater part of the tone is within

the usual amount of variability from the standard for the tone being sung.

In this connection, it may be said that corrections during the course of the singing of the tone are relatively infrequent. Even when the subject knows, as shown by the introspective records, that he is singing the wrong tone, he usually finds it difficult to change the pitch of a tone which has once begun.

The instances in which the error pertains to the entire tone are the most frequent. In such cases a large plus or minus percentage of error appears in the tables. When taken in relation to the pitch of the distracting tone it will be seen that the error is not always in the direction of the distraction. On the contrary, quite a large proportion of cases occur in which there is evidently a tendency to react in a direction opposed to that of the distracting tone.

A good instance of this kind is where Fn. was given a standard tone of 126.6 vibrations, followed by a distracting tone of 80 vibrations, Table XXII., page 277. Instead of the result being a sung tone of less than 126.6 vibrations, there is the large error in the other direction of 64.2 per cent. Again the same subject sang B (120 vibrations) followed by distracting tone of 135.6 vibrations, 3.6 per cent lower than the standard, Table XXII., page 277. When it is considered that the general tendency is to sing the tone higher than the standard, and that this tendency is especially marked in the lower notes, the negative error is the more noteworthy. Other instances of a similar kind occur and with other subjects. The majority of tones in which distractions plainly occur are, however, in the direction of the pitch of the disturbing tone.

In Table XXX., page 285, the results of the foregoing tables are condensed so as to show their main features. There is given the standard tone and the percentage of error when no distraction is present, followed by the statement of the per cent. of error in the tone sung when a distracting tone is used, the distracting tone being indicated in each case above the percentage of error.

Where effects of distraction are apparent they are indicated in three ways, corresponding to the three ways in which

the distraction makes itself felt. Thus the letter ^{x} indicates a tone where the tone actually sung is in an opposite direction from that of the distracting tone; a mark ^{y} indicates that the sung tone is in the direction of the distracting tone; and a mark ^{z} indicates that the effect of the distraction appears only in the early part of the tone. The detailed evidence for the conclusions respecting the cases in which distractions are effective appears in the foregoing tables.

TABLE XXX.—Subject Fn.

Standard.	Percentage of Error Without Distraction.	Percentage of Error With Distractions.				
C =126.6	+ 3.3	C♯=135.6 + 6.2^{X}	E =160 + 2.6	C♯=271.8 + 4.5	E = 80 +64.2^{Y}	
B =120	+ 2.1	C♯=135.6 — 3.6^{Y}	D =144.2 + 1.4	C♯=271.8 + 0.8	D =286.2 + 2.5	
G♯=200	+ 4.0	C =126.6 + 2.2	A♯=225 + 2.7	C =255.4 + 1.4	A♯=112.1 + 9.0^{Y}	Stamp —1.6^{Z}
F =170	+ 2.9	G =187 — 1.6^{Y}	D♯=302.8 + 1.8	G = 93.7 + 0.7	D♯=125.4 + 2.3	Stamp +0.5^{Z}
A =107.1	+ 2.7	C =126.6 + 0.1	C♯=135.6 + 2.3	C =255.4 + 4.1	C♯=271.8 + 6.9^{X}	Stamp +0.3^{Z}
A♯=112.1	+ 8.3	C♯=271.8 + 3.7^{Z}	E =160 + 4.6	A♯=225 + 4.7	F = 85 + 2	
D♯=302.8	+ 1.4	D =144.2 — 2.3^{Z}	D =286.2 + 2.5	B =120 + 1.7	B =240 + 2.1	
G =187	+ 4.9	G♯=200 + 4.3^{Z}	C =255.4 + 4.3	G = 93.7 + 4.4^{Z}	C =126.6 + 5.1	
G♯=100	+ 3.6	D♯= 75.5 + 5.2	G = 93.7 + 4.8	D♯=122.4 + 4.8	G =200 + 5.0	
C♯=135.6	+ 0.2	C =126.6 + 2.4	D♯=152.4 + 2.3	C =255.4 + 2.7	D♯= 75.5 — 5.9^{X}	
D =144.2	+ 3.7	E =160 + 0.7	G =187 + 0.9	G = 93.7 + 1.2	E = 80 + 0.4	
A =214	+ 2.7	C =255.4 + 2.1	B =240 + 2.1	C =126.6 + 2.1	B =120 + 3.1	
E =160	3.3	E = 80 — 0.3^{X}	F =170 + 1.6	C =126.6 + 2.0	C =255.9 + 0.9	

Subject J.

C =126.6	+ 6.2	High Sung Tone. +46.8[X]	C♯=135.6 + 7.8[X]	C♯=271.8 +33.3[X]	A =107.1 +24.3[Y]	Stamp —2.5[Z]
E =160	+13.0	F =170 +42.2[X]	C =255.4 +24.6[X]	C =126.6 +12.3	F = 85 +28.5[Y]	High Sung Tone. +47.0[X]

Sang High Tone.

C =255.4	+ 1.2	C♯=271.8 + 7.2[X]	D♯=302.8 +19.1[X]	D♯=152.4 +17.5[Y]	A♯=112.1 + 2.5

Subject Ce.

A =107.1	— 0.8	C♯=135.6 +16.3[X]	D♯=152.4 No dis.	D♯= 75.5 No dis.	A♯=112.1 No dis.
E =160	+ 0.6	F =170 No dis.	D♯=302.8 No dis.	F = 85 No dis.	D♯=152.4 No dis.
D =286.4	+ 1.8	D♯=302.8 No dis.	Stamp + 1.8[Z]	G = 93.7 No dis.	G =187 No dis.

Subject Cg.

E =160	+ 1.3	G = 93.7 No dis.	C♯=271.8 No dis.	F♯=178.1 No dis.	D♯=152.4 No dis.
C =271.8	+ 1.8	D =286.4 + 7.7[X]	D =144.2 — 4.1[X]	C♯=135.6 No dis.	C =126.6 No dis.

Subject G.

E =160	+ 1.0	D♯=302.8 —12.1[Y]	C =126.6 —21.7[X]	F =170 + 7.6[X]	D♯=152.4 +16.3[Y]
B =240	+ 1.2	C =255.4 No dis.	D♯=302.8 No dis.	C =126.6 No dis.	

Subject P.

E =160	+ 1.0	F =170 +37.1[X]	D♯=302.8 + 33.9[X]	C♯=271.8 +37.9[X]	A♯=112.1 +35.2[X]	F=170 +9.7[X]
D♯=302.8	+ 0.7	D =152.4 No dis.	D =286.4 No dis.			
A♯=112.1	+ 4.7	C =126.6 +15.2[X]	A =214 +20.2[X]			

Subject Fs.

D♯=302.8	— 0.2	D =286.4 1.1(—100)	C =271.8 No dis.	F =170 No dis.
A =107.1	+ 1.9	A♯=112.1 — 2.9[Y]		
E =160	+ 0.2	F =170 No dis.		

The question now presents itself whether there is any relation between the distracting tone and the tone actually sung in cases where distraction has occurred. In order to show whether such a relation exists, the following table, Table XXXII., is presented. In this table there are arranged the principal cases of distraction of each subject. The standard is given in the usual musical nomenclature and following it the distracting tone and the tone sung. These are also denoted by the letters of the usual musical notation. The relation of these tones to each other with reference to harmony is expressed by the signs = and +. Thus B + C# = A# indicates that the standard B was followed by the distracting tone C# which is not in harmony with B, and that the tone sung was A# which is in harmony with the distracting tone. The tones of the lower octave from D# to D# are indicated by small letters, those of the upper octave by large letters.

TABLE XXXI.

Subject Fn.

c + c# = c#	b + c# = a#	a = C# = a#
c = E = a	G# + a# = A	

Subject J.

c + c# = c#	E + F + B	C + C# = C#
c + C# = F	E = C = G#	C = D# = D#
c = a = E	E + f = G#	C = d# = D#

Subject G.

E + D# = d#	E + F = f
E = c = c	E + d# = A#

Subject P.

E + F = F	E = C# = A#	a# + c = c
E + f = A	E + a# + A	a# + A = c#
E + D# + A		

Subject Cg.

C# + D = D	C# + d + C

Subject Ce.

a = c# + c

Subject Fs.

a + a# = g

In all, twenty-nine cases are here presented, in which the effects of distractions are plainly apparent throughout the tone.

In twenty cases, or about seventy per cent. of the total number, the distracting tone and the standard tones are discordant. The proportion of discordant distracting tones to harmonious distracting tones actually used was about equal, so that discordant tones are clearly more effective for the purpose of distractions than are harmonious tones.

Moreover, twenty-five cases of the twenty-nine, or eighty per cent., represent instances in which the distracting tone and the tone actually sung are harmonious. Of these nine are cases in which the sung tone is the same as the distracting tone and in two cases it is the octave of the distracting tone. In both these latter cases the sung tones are the octaves of the distracting cones which are nearest the standard.

It might be supposed that in the remaining cases the sung tone would be in the nature of a compromise between the standard and distraction. In only seven cases of the remaining fourteen, however, does this supposition hold good. Nevertheless there is in all of these fourteen cases, as has been seen, a relation of harmony between the distracting tone and the tone actually sung.

Let us now examine those instances in which distraction occurs in a part of the tone only. These will include, in the first place, those cases where the distraction is a tone from an organ pipe and makes its effect apparent in the early part of the sung tone only, and, in the second place, those cases where the noise caused by the stamping of the foot is the form of distraction.

The first group of cases involves corrective movements which invariably take place in the early part of the tone, generally within the first half second. They are, therefore, similar in type to those which have already been described in connection with the series of experiments where no set form of distraction was used.

The beginning of the tone may be in error either in the direction of the distracting tone or in the opposite direction. Thus, Subject Fn. begins to sing standard 112.1 vibrations with distracting tone 271.8 vibrations at 131.3 vibrations, but corrects it after three tenths of a second to 115 vibrations. On

the other hand, standard 302.8 vibrations is begun at 171.5 when the distraction is 144.2 and it is not until after nine tenths of a second that the pitch becomes as high as the standard, though there is a gradual rise in pitch during the whole of this period. The introspective record shows that in both these cases the subject was conscious of the error and its direction. This last remark is true, in general, of the tones under discussion and in this point these tones differ from some of the earlier tones where corrective movements took place.

The effect on the pitch of the tone of the sudden noise caused by stamping the foot is not always marked. It frequently happens, however, as in the first of this kind reported for Fn., that there is a sudden increase in the pitch of the tone about two tenths of a second after the noise. Thus, in this case, the tone increased in pitch from 172.3 vibrations to 180 vibrations and this pitch is maintained for another tenth of a second, when it drops to 174 vibrations and from that point oscillates in the usual manner about the average of approximately 170 vibrations. The sudden rise in pitch is more marked than are the usual variations and are clearly correlated with the entrance of the distraction.

Another point to be noted concerning this tone is the length of the tone. The table presents the figures for the whole tone, which is very much shorter than the tone usually sung. This is characteristic of all the tones sung under this condition of distraction. Moreover, in each such case, the tone as a whole is slightly lower than would be expected under ordinary conditions.

There remains to be reported a brief series of experiments in which it was designed to obtain a surer means of distraction than in the cases mentioned above. Subj. Fn. was asked to sing a certain standard tone. While he was engaged in singing this tone, another tone was sounded for a few seconds only, and at the close of the singing he was required to say whether the latter tone was higher or lower than the standard. It was found that in every case it was possible to state the direction of the distracting tone correctly.

A further complication was now added by asking the sub-

ject to sing the distracting tone immediately after singing the standard. It must be remembered that the distracting tone had been sounded for a very brief period, and that this had taken place while the subject was engaged in singing the standard. Nevertheless, he was able to sing the standard tone correctly, as may be seen from Table XXXII. Further, he was able later at least to approximate the distracting tone, though with some difficulty. The table gives three instances of this sort. The average of the tone sung in imitation of the standard is given first, followed by a number of measurements at the beginning of the tone sung in imitation of the distracting tone. The vagueness of the impression left by the latter tone is paralleled with the way in which the subject 'feels' for the tone when beginning it. After a few tenths of a second of uncertainty, however, he proceeds in the usual manner and with a fair approximation to the tone, which he is endeavoring to imitate.

TABLE XXXII.

SUBJECT FN.

Standard E = 160	Standard C = 126.6	Standard D = 144.2
Dis. F = 178.1	Dis. C♯ = 271.8	Dis. G = 186
E	C	D
162.9 (Av)	135.4 (Av)	145.0 (Av)
F	C♯	G
152.7	244.7	221
144.2	268.2	142.4
153	256.2	149.4
152.1	267.5	209.9
154.3	269.7	177.5
154.3	272.4	181.1
153.4	271.3	191.2
152	273.8	205
		197.5
		197.2
		197.5
		194.8

The most important results of the entire investigation may be summarized as follows:

I. In the singing of a tone a sudden marked rise in pitch usually occurs near the beginning of the tone. This rise in pitch is so general as to seem to indicate a universal tendency.

II. No tone is sung entirely uniformly. It oscillates in

pitch from period to period throughout its length in a somewhat irregular rhythmical fashion.

III. Very marked differences exist in different individuals with regard to their ability to imitate a standard tone. The subjects tested varied in the degree of accuracy in imitation of standard tones of different pitch from a small fraction of one per cent. to thirteen per cent. of error.

IV. There is manifest throughout a tendency to sing a tone higher than it should be sung. Thus the end of a tone is usually higher than the beginning and the sung tone is almost invariably higher than the standard tone.

V. Distractions when causing disturbances may affect the whole of the sung tone or only the beginning of the tone. In either case the effect of the distraction may be to cause the sung tone to vary from the standard (1) in the direction of the distracting tone; or (2) in the opposite direction from the distracting tone.

VI. Sung tones varying from a standard under the effect of distractions are usually harmonious with the distracting tones. When the distracting tone is inharmonious with the standard tone, distraction is more likely to occur than when the two tones form a harmony.

VII. A person may more or less successfully imitate a tone which he has heard when his attention was engrossed in singing another tone of a standard pitch.

VII. Conclusion.

The results of the investigations presented in the foregoing sections naturally divide themselves into three parts, viz.:

1. The singing of a tone when the effort of the singer is confined wholly to maintaining its uniformity;

2. The singing of a tone in imitation of a standard tone; and

3. The singing of a tone in imitation of a standard when distracting conditions are introduced by means of the sounding of other tones.

The explanation of the results requires a discussion of the relation between the type of reactions with which the investi-

gation deals and the nervous processes which lead to these reactions, and also a discussion of the various modifications which may enter into these nervous processes and consequently into the final form of reaction.

Even in the case of the simple tones, when the entire task of the subject is the uniform sustaining of the tone after it is begun, marked variations are to be found in the character of the muscular activity. These variations are of interest in throwing light upon the nature of the motor discharge which is their immediate cause.

As has already been pointed out in the course of the report, many of these muscular changes are not recognized by the subject. It does not follow from this fact, however, that the muscular changes have no definite relation to modifications in conscious processes. In order that the subject should be able to recognize these changes distinctly through introspection, it would be necessary not only that he should give attention to the sensory processes involved in the singing of the tone, but also that he should be able to give a certain surplus attention to the variations in his own reactions. The absence of introspective recognition of the variations, therefore, does not show that the process is a purely physiological process without relation to consciousness. It signifies merely an absence of perceptual recognition of the variations.

Even from the physiological point of view, the voluntary contraction of the muscles, such as would be called into play in the singing of any tone under even as simple conditions as those of the first series of experiments, is not as simple as might at first thought be supposed. The contraction is not uniform and therefore not due to a steady discharge of nervous energy into the muscles. It would appear rather that the nervous impulse is not continuous, but that it consists of a series of discharges rapidly following one another, the muscles responding by contraction to each discharge.

Investigators such as Helmholz have noticed that a muscle in the condition of contraction emits a sound of low pitch (about 38 or 36 vibrations per second). It was at first thought that this fact indicated the frequency of neural dis-

charge to the muscles, but Helmholz showed conclusively that the muscle sound cannot be relied upon for conclusions in respect to this rate. Helmholz himself set this rate at 19.5 per second. Various investigators have arrived at different conclusions in respect to this rate. Thus, Krönecker and Hall agree with Helmholz, but Schäfer concluded from his experiments that the period was one tenth second. Again Haycroft confirmed the time given by Helmholz as the period of the muscle tetanus, but found that this time is only a rough average of the frequency, the contractions themselves not being actually rhythmical. Haycroft's general conclusion is that "during a reflex or a voluntary movement, the muscles involved exhibit fascicular or other local movements due to uncoordinated discharge from the central nervous system and perhaps due also to variations in excitability or activity of the fibers or fasciculi affected."

These figures borrowed from the physiologists make it clear that muscular contractions, even in the voluntary movements of a simple kind, are subject to modifications which are the result of changes in the nervous condition. Reaction experiments give results which point to the same conclusion. Attention has already been called in earlier paragraphs to the fact that these irregularities in the vocal muscles are analogous to irregularities in the movement of the eye muscles and the muscles of the hand. Our own results argue against anything like an absolute rhythm of muscular contraction in connection with the vocal muscles. A period of 100 sigmas for making each measurement of the pitch brings out a more or less regular oscillation of the pitch. The measurements taken of tones for smaller periods show, however, that the rate of discharge is not constant even from moment to moment during the same tone.

The whole process of reaction and control may be described as one of constant nervous readjustment. All the factors of sensory excitation and motor response must be kept in constant equilibrium. This requires that there should be a continuous condition of active adjustment on the part of the subject. If the muscles tend to relax on account of their physical condition

to the point where the tone becomes notably different from that which the subject began to sing there will be a general readjustment, so as to recover the original pitch. The separate consciousness of the relaxation of muscles and the necessity of bringing them back to the original tone will seldom occur in the case of the subject who is sufficiently trained to maintain the reaction without separate conscious efforts. His attention will be entirely absorbed in the maintenance of the process and not in the observation of the process. We shall have, therefore, in the reaction itself the immediate physical parallel of the activity of attention without break or interruption and without any secondary introspective activity superimposed upon the primary process of reaction.

There will be one point in the whole process where the necessity of controlling the reaction is usually greatest and where in consequence the attention will be most keenly divided. This point will be at the beginning of the tone and, as has been shown in the results of all of the investigations, this is the point where the most characteristic changes in reaction appear. To a certain extent there is undoubtedly a physiological difficulty connected with the beginning of a tone. The muscles must undergo a change from a state of complete or partial relaxation to a state of tension. The higher the tone to be sung, the greater will be this tension and consequently the greater the physiological difficulty involved.

But even more significant than this purely muscular fact is the necessity of a general nervous adjustment which will bring the outgoing motor discharges to the desired level for the maintenance of a steady reaction of the kind desired. The conscious experience which a person has when he begins to sing a tone is entirely different from that which he has when the tone has been once thoroughly established. Among the changes which must occur in the nervous condition at the beginning of a tone are certain changes on the sensory side, due to the fact that as the tone begins to sound there are new sensations received from the muscles of the throat and new sensations in the subject's ears. These new sensations, together with the initial neural excitement, constitute a general sensory

motive for the reaction, the discharge to the vocal muscles resulting in a kind of nervous equilibrium. If the sound which enters the subject's ear is unsatisfactory for any reason, the equilibrium may again be overcome, so as to satisfy the subject's voluntary desire for the modification of the tone, but even where there is no separate consciousness of the necessity of readjustment there will always be an effort to bring the voluntary reaction and the sensory factors, which have aroused it, to the point where there is no excessive stimulation and no thoroughly incongruous form of reaction.

A general discussion of the nervous conditions which accompany attention has been undertaken by MacDougall in a series of articles in *Mind*.[1] These articles expound a theory of the physiological factors of the attention process and are very suggestive for our present discussion. MacDougall sets forth his scheme in the following words: "My scheme extends to the cell bodies of the neurones and to all their processes the theory of similarity of function that is accepted by most, in fact by almost all, physiologists as true for their axis-cylinder processes; and it assigns to the intercellular substances which, lying between such terminations of fibrils of different neurones or between such terminations and the bodies of other neurones, constitute the most essential parts of the synapses (or junctions of neurones), all those specific changes which are the psychophysical processes proper, the immediate physiological correlates or determinants of psychical effects; and it regards them also as the principal seats of those resistances, varied and variable in degree, which determine the passage of the excitation process in this or that direction and confine it to relatively well defined and narrow paths among the labyrinth of innumerable paths possible to it in the absence of such limiting resistances."

MacDougall's theory assigns to the synapses lying between the point of sensory stimulation and motor discharge various degrees of resistance corresponding to the degree of organization of the path involved. Each synapsis has a certain normal threshold value, but this value also varies according to the

[1] *Mind*, 1902, Vol. XI., p. 316; 1903, Vol. XII., pp. 289, 473; 1906, Vol. XV., p. 329.

degree of excitement in the neurones of which it forms the connections. Activity of the neurones tends to lessen the resistance of the synapses, while certain drugs, fatigue, ètc., have the opposite effect. The degree of consciousness, then, according to this theory, instead of being related to the openness of the motor channel, depends upon the resistance offered by the synapses at various points in the course of the path involved. It is accordingly almost the exact converse of the theory of Münsterberg.

If now we wish to represent what takes place during the singing of a tone under the general scheme already presented. it may be expressed as follows. The voluntary contraction of a muscle corresponds to a central excitation in the motor area of the brain, causing a discharge into an afferent nerve leading to the vocal muscles. Now under condition of excitement it is one of the functions of all neurones to produce nervous energy at a rapid rate. The beginning of the supply of such energy is ultimately dependent upon the stimulation of a sense organ, but the supply becomes reënforced by the activity of all the neurones subsequently excited.

The discharge of the neural excitement, above referred to, into the vocal muscles causes contraction of these muscles. The contraction of the muscles in turn stimulates the afferent neurones leading from these muscles and thus reënforces the amount of available energy. This excitement returns to the muscle by way of a subcortical center, thus establishing what James has called a 'motor circle.' The return to the starting point inaugurates a fresh movement, which returns as before to the muscle. In this way the contraction of the muscles is maintained. If we regard the rate of this motor discharge as roughly approximating ten per second, a corresponding period of maximal contraction and partial relaxation may be looked for in the muscle.

A possible explanation of the sudden rise in pitch at the very beginning of the sung tone is also suggested by the same fact. If the theory is correct that the amount of available nervous energy is thus reënforced by that supplied from excitement of the sensory neurones leading from the muscles, then

the amount of energy to be used in the contraction of the muscles must be increased the moment after the contraction begins. This energy will be relatively more effective in increasing the height of the tone at its very beginning.

Moreover, at the beginning of the singing of any tone, still another sensation (auditory) is added over and above those which have been present the moment before. The sound of the sung tone increases the amount of available nervous energy. The most natural path of discharge of this energy is then the motor channel, already open. Hence at the moment after the singing has begun the amount of nervous discharge into the vocal muscles is suddenly increased from these two sources, leading to greater tension and an increase in the pitch of the tone.

Turning now from the simple process of maintaining a tone to the more complex processes involved in the imitation of a tone and in singing it in the face of a distraction, we see in view of the foregoing discussion that the maintenance of the equilibrium between the sensory motives for action and the motor discharges leading to muscular contraction becomes a very much more complicated process. In the case of imitating a given tone, for instance, the sensory stimulus consists not merely in the general directions that have been given to the reactor to produce a tone, but also in the auditory sensations which are intended to govern the specific character of the reaction; viz., the pitch of the sung tone.

The establishment of an equilibrium for which this sensory stimulation is the motive will take place in a similar manner to that in which it occurs in connection with the simple reaction. The two cases do not differ essentially in their fundamental type. But owing to the new sensory factors involved we may except in the latter case more frequent readjustments in the established equilibrium and hence larger variations in the reactions. In these more complex cases, too, we may expect greater individual differences due to the training of the subjects, some subjects being prepared by their earlier experiences to follow the specific instructions, while others will be more or less unprepared to do more than they did when there was no

specific tone to imitate. The accuracy with which the sung tone corresponds to the pitch of the standard depends upon the degree to which organization has been carried on in each individual.

When in addition to the standard tone, to be imitated, a further stimulus in the form of a distracting tone is introduced, it is to be expected that some disturbance of the established equilibrium will take place. This disturbance, however, will not necessarily be shown in a modification of the pitch of the sung tone. An equilibrium which is well established may maintain itself in the face of newly given stimulations if provision has been made for just such an emergency. This will often be the case under the conditions of laboratory experiments when the subject understands the significance of the distracting tone and when there is no vital or practical interest for the subject in the fact of its appearance. It is conceivable that, when a muscular coordination has once been established that the additional stimulus may simply reinforce certain of the motor discharges without leading to any modification in the form of that part of the reaction which relates to the pitch of the tone. In such cases the sounding of the distracting tone may necessitate a new equilibrium, but the features of the old equilibrium essential to its pitch are included in the new equilibrium as its most essential feature. The excessive stimulation from the added stimulus becomes a sensory motive for a discharge not into those motor channels connected with the vocal muscles, but into some other channels such as, for instance, those muscles controlling the volume of the tone, or it is drained off in the way of a more general motor excitement in various parts of the body. Other cases may occur as in connection with the series when a sudden loud noise was the form of the distraction, when the excessive stimulation thus aroused results in a temporary reinforcement of the motor discharges into the vocal muscles, but the pitch of the tone is not permanently affected.

If, however, the subject gives sufficient attention to the distracting stimulus to affect the pitch of the tone, it does not necessarily follow that the reaction will exhibit a modification

of the final vocal tone in the direction of the distraction itself, for in the effort to bring about a readjustment which shall include the distracting tone, the reactor may resist the tendency towards a new tone with such completeness as to modify his reaction in a direction exactly opposite to that of the new stimulus. This, as we have seen, occurs in a number of cases in the experiments reported. Analogous experiences occur in ordinary life. Instead of looking toward a bright light which distracts the subject, it is not at all unusual to turn away from this source of distraction. One may redouble his energy in reading if he is attempting to overcome the distraction of an external sound. The new stimulation is in both of these cases treated in such a way as to be eliminated from the equilibrium of attention rather than accepted as the guiding factor.

A fact of importance brought out in the results of the experiments is the tendency, when the distraction is effective, to sing tones which are harmonious with the distracting tone. It is by no means a new fact that the motor reactions to tones are intimately related to all the forms of discord and harmony. It may be advantageous in future discussions of the nature of harmony and discord to emphasize this relation to a still greater degree. There can be no doubt that the vocal cords will differ in behavior at different pitches in a manner analogous to the way in which different tones of the scale differ from one another in physical vibration and in their effects upon the basilar membrane.

Theories of harmony in the past have laid great stress upon the physical and sensory fact of vibration. A comparative study of musical statistics will show, however, that the development of the comprehension of musical harmony has taken place within a relatively short period. Furthermore, it is extremely unlikely that there have been modifications in the structure of the ear parallel to this development. It is not easy to believe that there is sufficient difference in the structure of the ear of the Chinaman and the American to account for the difference in their comprehension of musical harmony.

The results obtained from this investigation point to a line of consideration which it would be profitable to carry further.

The maintenance of an equilibrium which has been established between a sensory stimulation and a motor discharge is more difficult when an added sensory stimulation is of such a pitch that the motor discharges are inharmonious with the added stimulation. In other words, when the motor discharge is readjusted so as to establish an equilibrium that shall include the new stimulation and the earlier stimulations as well, there is an adherence to the principles which we know as the principles of harmony. It may, therefore, be said that there is a close relation between the recognition of harmonies and the motor processes and it is not necessary to believe that there is any necessary reference in this fact to the separate vibrations of the sensory stimulation or of the motor impulses. It does not seem necessary to assume that there is recognition of the tones from the separate vibrations.

The facts are explicable on the theory that the law of muscular adjustment must be in general conformity with the law of rates of vibration. This conformity is not the result of any conscious recognition of this relation, but is due to the fact that the muscular reaction, while it must on the one hand stand in some relation to the nervous conditions which control it, will naturally, on the other hand, be related to the facts of physical vibration, since the result of the muscular contraction is always physical vibration.

PRELIMINARY EXPERIMENTS ON WRITING REACTIONS.

BY FRANK N. FREEMAN, M.A.

Assistant in Psychology, Yale University.

This paper reports a method of recording the movement made during the drawing of a line by means of a pencil as in writing. From this record the details of the form of the movement, the rate of the movement, and the changes in pressure which accompany the movement can be examined with great exactness. The measurements here reported are preliminary to an examination of different forms of writing and individual variations in writing movements. They give the time involved in starting simple and complex movements of different forms, and the time required to stop a vertical or circular movement when these are under way. In general it was found that stopping a movement involves more complex adjustments than starting, and when the final form of the movement is complex the time of starting is appreciably lengthened.

Apparatus.

The apparatus used in this experiment was devised for the purpose of making a general investigation of the writing coordination. The investigation has reached a stage which justifies a preliminary report giving a description of the apparatus, together with some account of experiments on the fundamental modes of reaction involved in writing, namely reaction by stopping, starting, and changing the direction of movements made with a pencil.

The method is essentially a modification of the kymograph method. A strip of paper, *B*, Fig. 76, travels across the writing surface, *A*, on which the reactions are made. As a moving strip is not a convenient surface upon which to write, a typewriter ribbon is placed above the moving strip and above the ribbon is a fixed sheet of paper on which the reactor writes. Thus, when the subject writes on the fixed sheet, the moving strip underneath takes the record from the ribbon as though the strip were being written upon directly, and at the same time the subject has the record of what he is writing before him as usual and is in no way discommoded by the movement of the

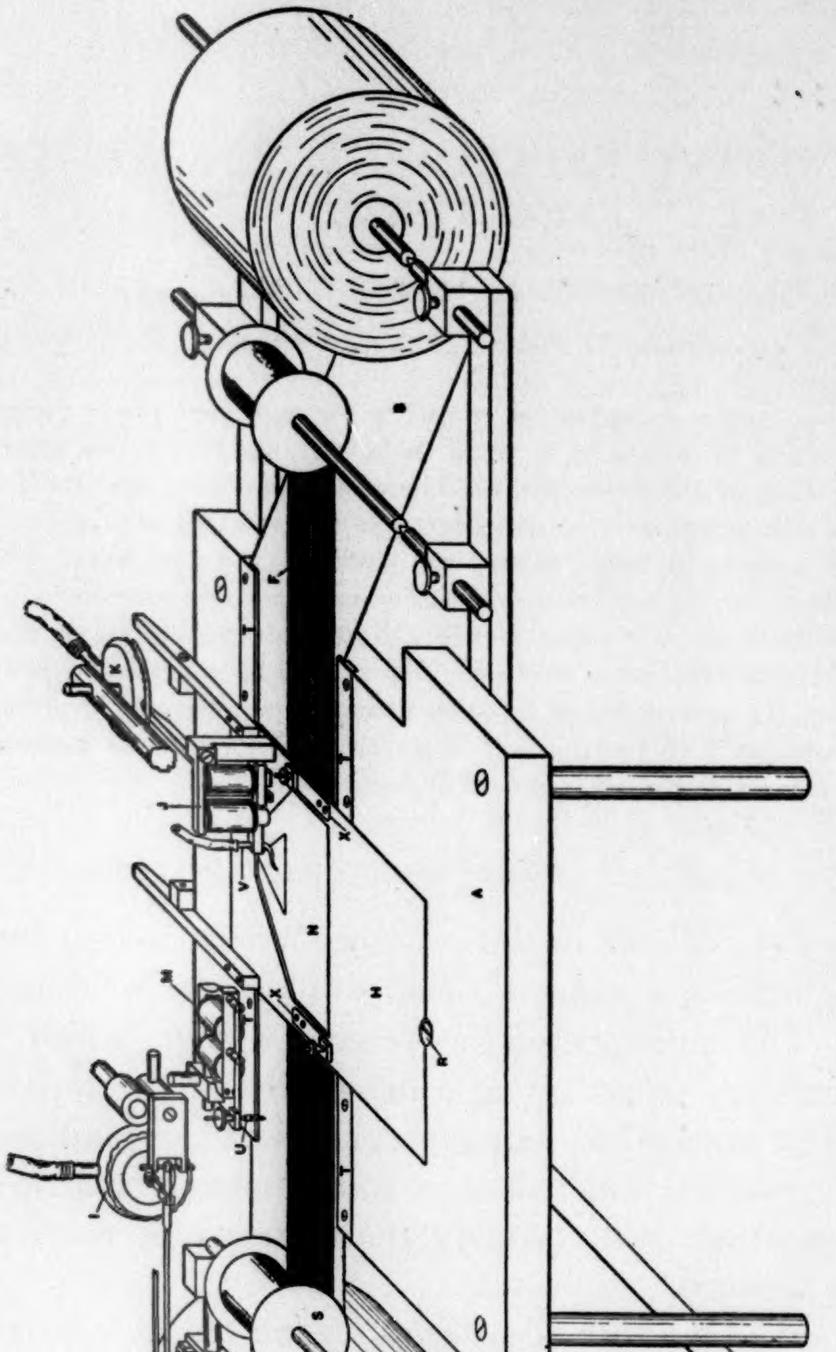


FIG. 76. (Reduced to one-sixth.) General view of apparatus. For detailed description see text.

strip underneath. The record on the upper sheet we may call the primary record and the record on the moving strip the secondary record. The sheet of paper and the strip, on which the primary and secondary records respectively are taken, will be referred to as the primary sheet and the moving strip. A sheet of carbon paper was first used for the transfer of the record, but it was found that the carbon soon wore off, especially when the pencil was held in one place for any length of time, and the ribbon moving at a slow rate was substituted.

Fig. 76 gives a general view of the apparatus. Two bars extending from the metal base *A* support the roll of paper and the spool of ribbon from which the strips *B* and *F* are unrolled. *B* and *F* pass across plate *A* to the drum *C* and the spool *S*, the latter being supported by the post *Q* and one not shown in the figure. The drum and spool are driven through spur gear connections by the shaft *G*, which is in turn connected with a driving shaft. The apparatus is coupled into the driving shaft and uncoupled by a friction clutch of the type shown in Fig. 97, page 371, of this volume. The apparatus can thus be set in motion at full speed, and it can also be instantly set free when the record is complete. The motion thus obtained is very regular and easy to control. The motion of the typewriter ribbon spool is greatly reduced from that of the drum, with the shaft of which it is connected by a belt.

In order to hold in position the primary sheet of paper on which the reactor writes and to support the hand, a plate, *H*, is placed over the primary sheet. A rectangular opening, *N*, is made in this plate to expose a writing surface on the primary sheet. The plate, *H*, is hinged at the back of the main base by two bars, so that it may be raised to insert the paper. Fig. 77 shows it raised from the base. Two small pins, *O, O*, pierce the primary sheet of paper and fit in the hole *R*, and one not shown in the figure, and keep the primary sheet from slipping when the strip and ribbon pass beneath it. These pins are above and below the moving strip. In order to get an even writing surface the plate is set into the main base, so as to lie flush with the general surface, and is held down by a screw, *R*, Fig. 76. The moving strip of paper and ribbon are also

set below the surface in a channel which is cut in the main base. Two guides, *T, T,* on each side of the moving strip keep it straight. The upper ones are slightly adjustable, so as to suit minor differences in the width of the paper.

In order to obtain a record of the relative position of the primary sheet and the moving strip, two pencil points are set through holes in the hinged plate, *H*. These pencil points make two dots upon the primary sheet and two lines on the strip. The points are shown in Fig. 76, *X, X,* and the holes through which they project in Fig. 77, *E, E*. The points are set on two flat springs and are adjustable with screws, so that they may be set against the paper with varying degrees of pressure.

Since the speed of movement of the strip is not perfectly uniform, an electric marker writing tenths of seconds, *J,* Fig. 76, is pivoted to a post set on the hinged plate, *H,* and is adjusted by a screw so as to bring the writing point against the paper. It writes through an opening in the primary sheet upon the moving strip beneath. In order to keep the primary sheet from blotting this line, it is held up from the moving strip by two small brass clips, *T,* Fig. 77, and the time line passes between these clips.

The glass pen, *V,* Fig. 76, which is used for the time record, is a form of capillary pen. To prevent clogging and uneven flowing, the opening in the point is made fairly large and the flow of ink controlled by a regulating air chamber. The upper end of the glass tube is inserted in a rubber tube which allows the point to move freely, and the tube is connected with a tambour. The rubber head of this tambour can be raised or lowered by a screw, and the ink thus made to flow slower or faster.

In order that the relation of the reactor's record to the time line might be easily determined, the reactor was required in this experiment to make all movements holding the pencil against guides which were placed in a known relation to the time marker. These guides can be set in the opening, *N*. One is a straight strip of brass which is a guide for the vertical line and the other a circular piece of brass which is a guide for the circle. The circular guide is about 4.5 cm. in diameter.

In order to get a record of the time when the signal was given in the reaction experiment, a second marker, *M*, Fig. 76, was clamped to the writing base and made to write on the moving strip. This marker is 14.5 cm. from the first marker, *J*, and by making a correction of this distance in reading the record, it can be correlated with the time marker and the traced record. This marker writes with a special form of pen.

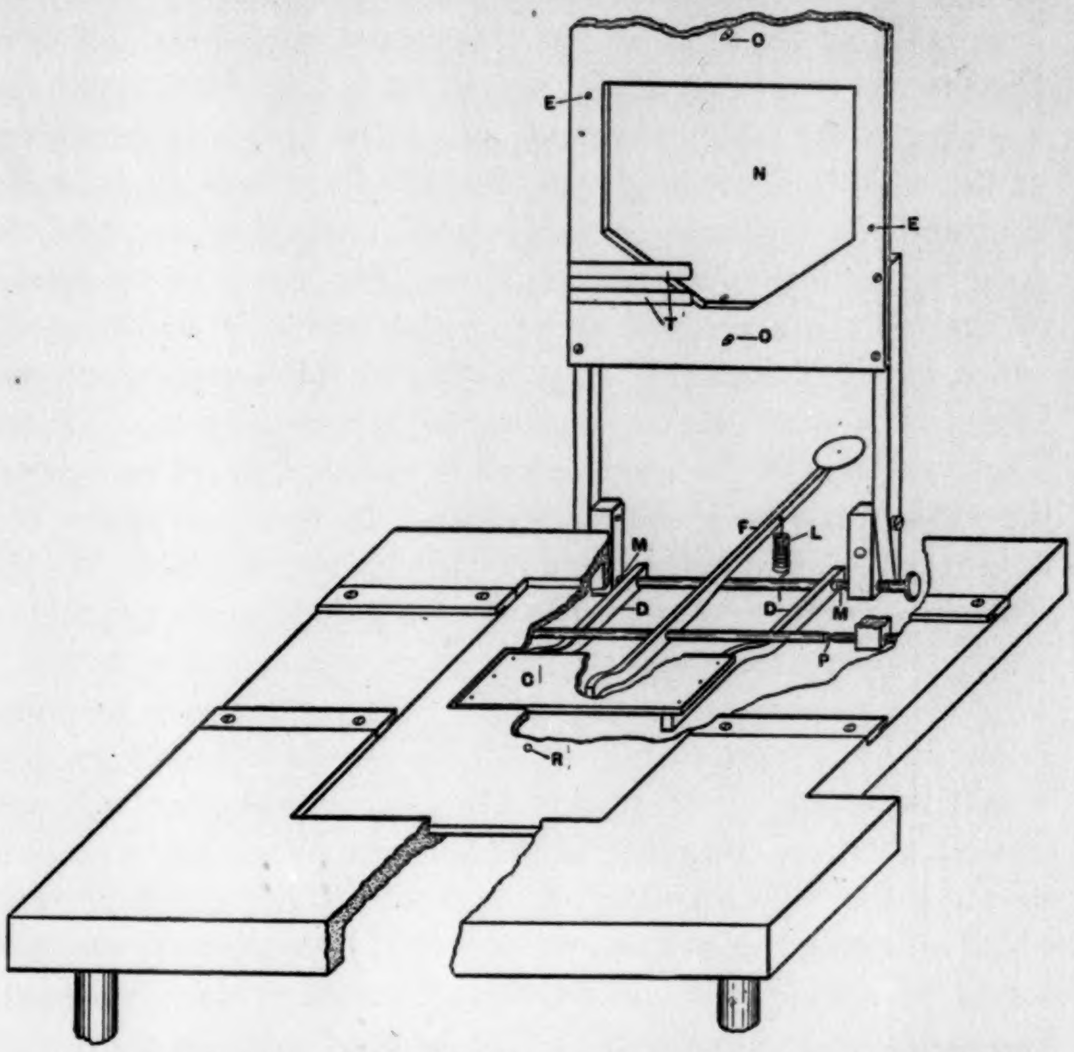


FIG. 77. (Reduced to one-fifth.) Supplementary view of apparatus.

This pen, *U*, Fig. 76, is made from a conical piece of steel by drilling a hole through the base and cutting a slit from this hole to the point. The marker is in circuit with a telegraph sounder which gives the stimulus for the reaction. Both marker and sounder are operated by a mercury key, thus giving on the moving strip with the other records the time of occurrence of the sound to which the subject is to react.

Besides the speed of the reactor's movements, it is desirable that the variations in the pressure of the pencil against the paper should also be recorded. The arrangement for securing a record of the pressure is shown in Fig. 77. Under the paper upon which the reactor writes is a small table *C*, set into an opening in the base. The opening in which this table is set is situated immediately below the opening, *N*, of the hinged plate, so that the table occupies all of the writing space. The table is capable of an upward and downward movement, for it is fixed to the two bars, *D, D*, which are in turn fixed to the axis working in the pivot joints, *M, M*. The radius of movement of the table is, accordingly, the length of the bars *D, D*, or 17 cm., and the direction of movement during a slight displacement is practically in a vertical line. The extent of movement of the table is magnified five times by means of the lever, *F*, which has its fulcrum at *P*. A disk on the outer end of this lever is in contact with the rubber of the tambour *K*, Fig. 76. The inner end of the lever, which is rounded, bears up against the table, making a sliding contact. In order to lessen the weight and consequent inertia of these parts, the table and its connections are made of aluminum. The long arm of the lever nearly balances the weight of the short arm together with the table and its supporting bars. The slight residue is counterbalanced by a light spring, *L*. This can be adjusted so that it will bring the table quickly back to position, but will not prevent a delicate response of the lever to a very light pressure on the table. The spring, *L*, as well as the tambour, with which a disk on the end of the lever is in light contact, are supported by a rod, shown in Fig. 76, fastened to the main base. The tambour is adjustable so that its head will just touch the lever when the table is in position. This apparatus responds with delicacy sufficient to easily record all the ordinary changes in pressure during writing. Tests with weights show that it will record changes in pressure of from 20 to 300 grams.

The remainder of the apparatus for recording pressure is shown in Fig. 76. The receiving tambour, *K*, is connected with the recording tambour *I*, which writes on a long strip of smoked paper, *E*. This strip travels over the drum, *D*, and another

drum 3.5 meters away. The drum *D* is clamped by an adjustable screw to the same shaft as the drum *C*, so that both of them can be driven together, or either one can be run separately by loosening the screw which clamps *D* to the shaft. Above the tambour pointer is a fixed pointer which traces a straight line with which to compare the pressure curve. The pressure curve is correlated with the speed curve on the moving strip, *B*, by means of one pointer of the double marker, *L*, which is in circuit with the marker, *J*, on strip *B*. The time of the reaction signal is also recorded on this smoked record by the other pointer of the marker, *L*, in the same circuit with the sounder.

To sum up then, by means of the apparatus above described, one can obtain two records, one showing all the details of the rate, and the other all the details of pressure in any writing or drawing movement. The following description will show the method of interpretation of the records secured with this apparatus.

METHOD.

Fig. 78 shows the simplest type of a record of speed. This is a record made on the moving strip of paper by drawing a vertical line on the primary sheet directly below the time marker. In order to make this record as simple and exact as possible the vertical guide was put on the hinged plate and the reactor was required to follow the guide in drawing this line.

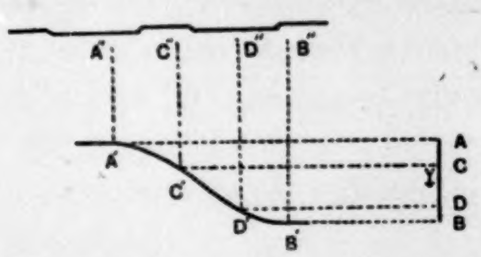


FIG. 78. (Reduced to one-third.) Illustration of the method of measuring the speed of a vertical line or part of a vertical line which is directly under the time marker. For detailed explanation see text.

The line *AB* represents the record on the primary sheet and *A'B'* and *A"B"* the record on the moving strip, *A'B'* being the record from the typewriter ribbon, *A"B"* the time line. All the dotted lines in Fig. 78 are inserted after the record to aid

in interpreting the full drawn lines which constitute the record proper. In order to measure the time occupied in drawing the whole line *AB*, we merely have to compare the whole tracing, *A'B'*, with the corresponding part of the time line, *A"B"*. The intervals of the time line indicate tenths of a second, and the drawing obviously occupied in this case about $1\frac{1}{4}$ tenths of a second or 125 σ. If now, instead of measuring the time of the whole line we wish to find the time consumed in drawing any given part of the line shown on the primary sheet of paper, *CD*, Fig. 78, we need only to project that portion of the vertical line to be measured upon the record taken on the moving strip. The projection of the vertical line upon the oblique record requires that the vertical line and the record be brought into the relation in which they were when the record was made. In order to do this, the reference points on the sheet made by

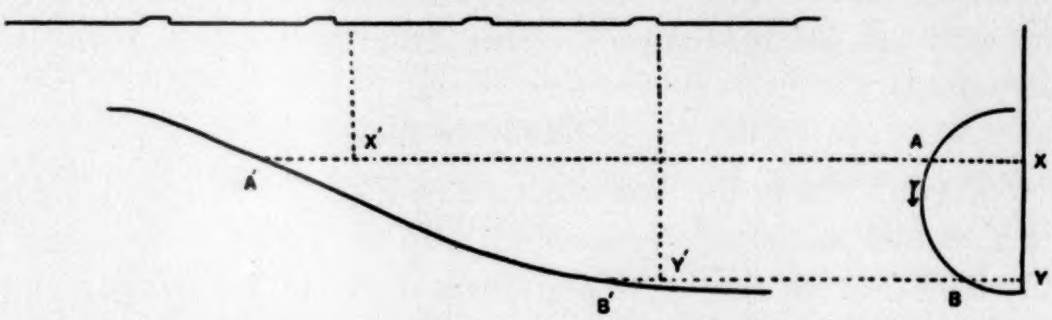


FIG. 79. (Reduced to one-third.) Illustration of the method of measuring the speed of part of a curve. For detailed explanation see text.

the pencils mentioned in describing the apparatus, are superimposed on the reference lines of the strip. Horizontal lines are now drawn from the beginning, *C*, and end, *D*, of the part of the vertical line to be measured, to cut the oblique line of the strip at *C'D'*. From this stage on the process is the same as in the first case.

The above is the simplest possible case. Very often the line is not drawn directly under the time marker. In such cases a correction must be made, in reading the record on the strip, equal to the horizontal distance between the marker and the line on the primary sheet. In this case the projection of the primary line, *AB*, Fig. 79, upon the secondary line, *A' B'*, is found as before. Then the horizontal distance from the

primary line to the marker, AX, is measured, and the same distance taken from the traced line, $A'X'$. This brings the record of speed under that part of the time line which was made at the same time as the part of the line to be measured. Similar correction is made at B' by deducting a distance on the time line equal to BY. The time is now measured on the time line between points vertically above X' and Y'.

This figure shows the principle of correction when it becomes necessary to measure the time of any horizontal or oblique movement. Evidently in all such cases the distance between the two points on the secondary record on the moving strip represents not merely the distance through which the strip travels while the line is being drawn, but also the negative or positive change in horizontal position of the pencil point as it makes the line. The change in position of the pencil point must, therefore, be allowed for either negatively or positively in order to get the simple time determination. In order to make the necessary correction in reading the record, if the pencil moved in the same direction as the strip, this primary pencil movement must be added to the distance between the two corresponding points on the strip; if the pencil moved in the opposite direction, the distance must be subtracted. In the case of an oblique line the horizontal distance through which the pencil traveled must be allowed for, as in the case of the horizontal line. In projecting A and B in Fig. 79 to A' and B', the distances $A'X'$ and $B'Y'$ were recognized as unequal. The greater length of $A'X'$ shows that the pencil moved obliquely to the right as the line AB was drawn. Hence, a part of the record $A'B'$ is due not to the movement of the traveling strip, but to the movement of the pencil.

A typical record showing details of a simple reaction is presented in Fig. 80. S is the record of the reaction signal which is made by the second marker, M, Fig. 76, writing on the moving strip, B. In order to bring this signal into relation with the time line a correction has to be made equal to the distance between the two markers. Measuring off this distance on the time line, we find that the signal was given at a point on the time line corresponding to S'. The point at

which the reaction occurred is indicated at *R*. The point where the signal is given, thus corrected, will hereafter in all cases be indicated by the letter *S*, and the point of the reaction by *R*.

The error in reading the records was well within three thousandths of a second. Each interval of the marker record, that is, each 100 σ was in the records 30 mm. or more in length. Accordingly, a distance corresponding to one sigma was at

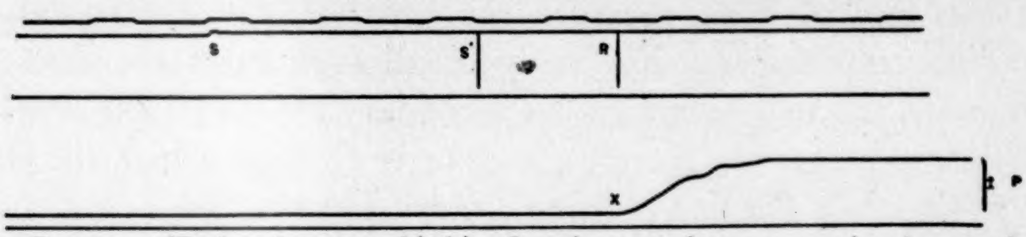


FIG. 80. (Reduced to one-third.) Speed curve from a reaction by starting a vertical movement upward, showing at *P* the line as actually drawn, in the upper line the time record, at *S* the record of the signal for reaction, and *S'* the corrected position of *S* with reference to the time line. *R* corresponds to the point *X* where the reaction began. The reaction, measured by the part of the time line between *S'* and *R*, in this case was very fast, occupying about 125σ.

least one third of a millimeter in length. This could be read with great precision, the measuring apparatus reading directly to tenths of a millimeter. Allowing for all possible errors up to a full millimeter, the error of measurement would fall well within three sigmas.

The reactions reported in this paper consisted of various fundamental movements which occur in all complex writing activities. The reactor held a lead pencil in his hand in the ordinary position for writing and drew lines of various kinds across the primary sheet of paper. The results of this experiment, therefore, constitute an introduction to the study of writing. They also have independent value as showing certain characteristics of various types of reaction movements. In ordinary reaction experiments the movement which constitutes the reaction is very simple, like lifting the finger from the key, and very little is known of the subsequent or antecedent motor changes. Even these simple reactions may very advantageously be subjected to analysis, as has been shown by a number of recent investigations. The present investigation serves to describe a method of complete analysis and to supple-

ment the analytical work already done on simple reactions by an analysis of more complex reactions. In the second place the analysis was made complete in two directions in that it includes both horizontal movements and pressure changes. Pressure changes may precede, accompany, or follow the horizontal movement in which the main reaction consists. The secondary phases of movement often throw light on the character of the whole process, as subsequent discussions will make clear.

In the third place, we may by this method study reactions of a type which are ordinarily neglected in reaction experiments, namely, those which consist in stopping a movement. Previous experiments have usually dealt altogether with reactions by starting a movement. We may refer to those common movements as starting reactions. In distinction we may designate reactions by stopping a movement as stopping reactions. In ordinary behavior stopping reactions are as constant and as important as starting reactions. In fact, most reactions are a combination of the two. This is particularly the case with the reactions which occur in writing, as will be seen when one considers a case in which the direction of a line is changed abruptly.

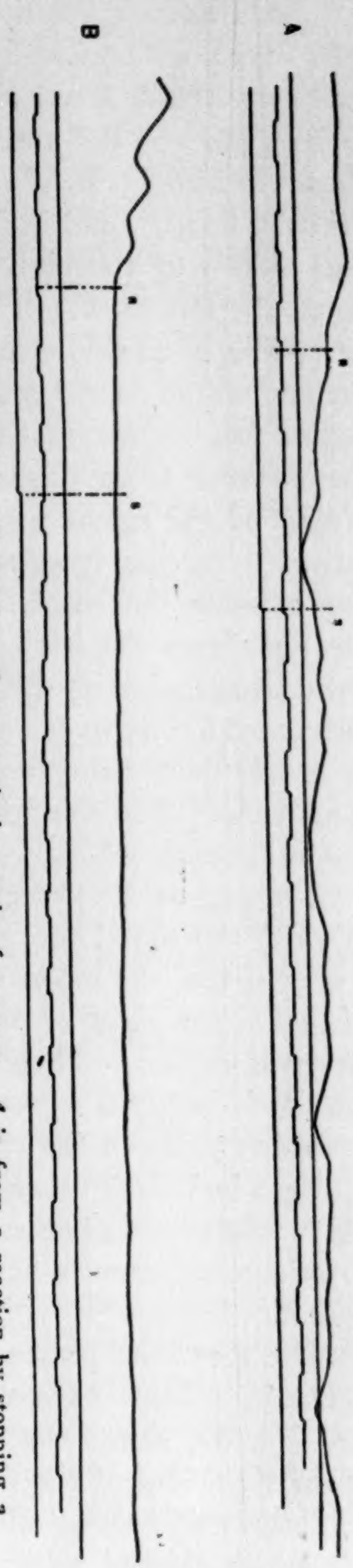


FIG. 81. (Reduced to one-fourth.) Illustration of two typical records of pressure. *A* is from a reaction by stopping a vertical movement and *B* from a reaction by starting a vertical movement.

Since starting reactions are of the more commonly investigated type, we present first a typical case of such reaction. A specimen of the speed record for a starting reaction is shown in Fig. 80, and the pressure record for the same movement is shown in Fig. 81, *B*. In the speed record, Fig. 80, we have the primary line, *P*, and the secondary curve, *X*. The curve consists merely of a straight line before the reaction begins—that is, on the left of *X*. This line is made by holding the pencil at a point, preparatory to the reaction. At the point, *X*, where the line on the record deviates from a straight line, the reaction begins and we may calculate the reaction time by comparing the distance from this point to the point which records the giving of the signal to react, with the time line. From the record after the reaction we can calculate the speed of the post-reaction movement. The more abrupt the deviation of the line from the horizontal, the faster was the movement. Other characteristics come out in the form of the record. In the record before us the movement exhibits marked irregularity in speed, there being two parts of the movement which are much slower than the rest, as shown by the wave form of the line at the right of *X*.

Turning to the pressure curve in Fig. 81, *B, S* is the point at which the signal was given and *R* the point where the reaction occurred, the record in this case being read from right to left. On the right of *S* some slight irregularities are seen in the pressure line. These are less obvious in the reduced figure than in the original record. These irregularities show changes in tension prior to the reaction. Similar facts were reported at length in Vol. I. (New Series) of these Studies (pages 141–184). In this experiment there are shown in addition to the variations in pressure before the reaction, those which occur after it.

The speed and pressure records for a stopping reaction are presented in Figs. 82 and 81, *A*. The first part of the speed line, Fig. 82, shows that a vertical movement is being made. At the right end of the record the oblique line changes into a horizontal; this shows the inhibition of the movement. The time which elapsed between the signal to stop and the actual

stopping can be measured as before. It is especially important to observe that the movement continued for some time after the signal, but is, especially at the end, modified in form. The pressure record, Fig. 81, *A*, which should be read from right to left, exhibits the changes in pressure which occur during a vertical movement, and the increase in the downward pressure after the vertical movement has entirely stopped. *S* and *R*, as before, indicate the giving of the signal and the reaction.

The experiments to be reported fall into seven groups. The details regarding these seven groups are as follows. In Series I. the reaction consisted in stopping a circular movement. The circular attachment was put in the opening of the plate *H*, Fig. 76. The reactor was required to move in an anti-clockwise

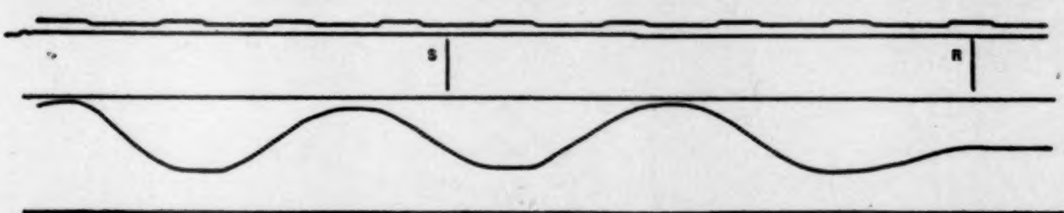


FIG. 82. (Reduced to one-third.) Speed curve from a reaction by stopping a vertical movement, showing in the uppermost line the time record, and in the second line from the top at the extreme left the signal to react. This is corrected to *S*. The line shows at the right of *S* the break in the circuit of the signal marker, which is not, however, significant. The third line from the top and the bottom line are reference lines. The line between the reference lines shows at the left a succession of upward and downward movements and at the right the stopping of these movements.

direction, keeping the point of the pencil against the inner edge of the guide. The movement was made at a rate of speed which was agreeable to the reactor, and varied from one to two revolutions a second. The reaction consisted in stopping the movement as abruptly as possible when the sound was heard.

In Series II. the reaction consisted in starting the circular movement which was used in Series I. The pencil was held at a point against the inner edge of the circular guide and at the signal the reactor began to trace a complete circle. In one half the reactions the point at which the movement began was at the extreme left side of the circle, and in the other half at the extreme right side.

In Series III. the reaction consisted in stopping a vertical movement. The vertical guide was put in the opening of the hinged plate. The reactor moved the pencil up and down against this vertical guide, tracing a line on the paper. The movements were made at the rate of about two double strokes per second and were from two to three centimeters in extent.

In Series IV. the reaction consisted in starting the movement described in Series III. The reactor held the pencil at a fixed point against the straight edge and at the signal made a single stroke. In half the cases the movement was made from the top down, and in the other half from the bottom up.

In Series V. the same vertical movement as in Series III. was made before the reaction. The reaction itself, however, consisted in changing the direction of the movement from the

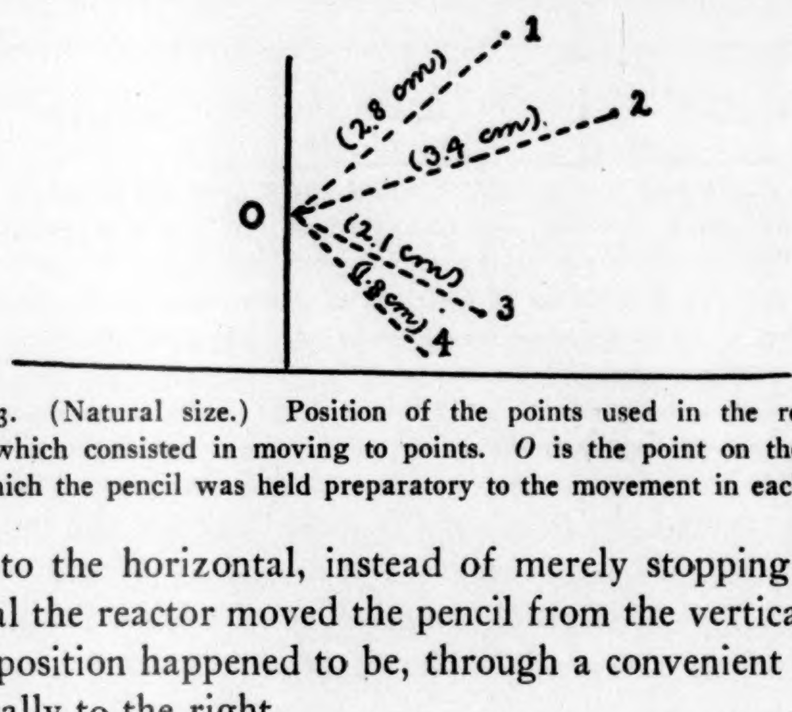


FIG. 83. (Natural size.) Position of the points used in the reactions in series VI which consisted in moving to points. *O* is the point on the straight-edge at which the pencil was held preparatory to the movement in each reaction.

vertical to the horizontal, instead of merely stopping it. At the signal the reactor moved the pencil from the vertical, whatever its position happened to be, through a convenient distance horizontally to the right.

In Series VI. the reaction consisted in moving from a fixed point, *O*, Fig. 83, which was directly under the time marker, to a dot which was placed on the paper. Four dots were used for successive trials in the positions and at the distances indicated in Fig. 83. The reactor was instructed to move to the point with one stroke.

In Series VII. the reaction consisted in starting to make a square or a circle. The pencil was held before the reaction

directly under the marker, as in Series VI. The square or circle as made are shown in Fig. 84. In half the cases the reactor started up and in the other half down.

In most of the reactions of all the series a warning signal

FIG. 84. (Natural size.) Types of the figures made in the reactions by starting to make geometrical figures.

was given by saying 'ready' from one to two seconds before the signal for reaction.

There were five subjects in the experiment, all of whom were trained in reaction work. They were Chas. H. Judd, E. H. Cameron, D. J. Cowling, C. A. Cockayne and the writer. They will hereafter be referred to by their initials.

RESULTS.

The results of the experiment fall under three general heads. First, the reaction times of the various series will be reported in thousandths of a second. Second, a description will be given of the form of the speed curve and the rate of its different parts. Third, a report will be given of the pressure changes which occur before the signal, between the signal and the reaction, and after the reaction.

The reaction times obtained in each of the series of the experiment are shown in Table I. This table gives the number of reactions, the average reaction time, and the mean variations for each reactor in each series. The total number of reactions and general average is also given for each series.

The mean variations are in some cases within ten per cent. of the average, but are usually larger than ten per cent. and in

TABLE I.

REACTION TIMES OF THE DIFFERENT SUBJECTS UNDER THE VARIOUS CONDITIONS.

Subject.	I. Stopping Circle.			II. Starting Circle.			III. Stopping Vertical Movement.			IV. Starting Vertical Movement.		
	No. reac.	Avg.	M.V.	No.	Avg.	M.V.	No.	Avg.	M.V.	No.	Avg.	M.V
C. H. J.	14	244	43	17	213	31	15	243	48	16	196	43
E. H. C.	12	239	58	15	171	18	10	256	69	10	186	25
C. A. C.							7	351	53	8	301	57
F. N. F.	9	253	20	18	187	40	9	306	43	12	175	16
D. J. C.	11	385	69	11	170	32	7	226	40	10	160	22
Avg.	46	278		61	187		48	271		56	198	

Subject.	V. Changing Direction of Movement.			VI. Starting to Points.			VII. Starting to make Geometrical Figure.		
	No.	Avg.	M.V.	No.	Avg.	M.V.	No.	Avg.	M.V.
C. H. J.	10	247	28	6	209	44	8	263	55
E. H. C.	10	312	47	11	233	26	11	223	38
C. A. C.	4	338	11	8	273	50	9	324	67
F. N. F.				8	230	23			
D. J. C.	10	403	71	10	198	34	9	183	30
Avg.	34	323		43	228		37	247	

several cases are about twenty per cent. The explanation of this large mean variation is probably to be found in the complexity of conditions which were imposed on the reactors.

A comparison of the stopping reactions with the starting reactions shows that the stopping reactions are markedly slower. Take first Series III., stopping a vertical movement, and Series IV., starting a vertical movement. The average of the stopping reactions is longer by 73 σ or 37 per cent. than the average of the starting reactions, and the average for each subject shows a like difference. The same general result appears in the starting and stopping of circular movements. In dealing with the vertical movements, it was thought that possibly the pause and abrupt changes in direction in the vertical movements prior to the particular movement in which the stopping occurred, might be the cause of the delay in stopping when the signal was given, and the circle was accordingly introduced to secure a movement without pauses or abrupt changes in direction. By comparing the results of Series I. and II., it will be seen that there is a still greater difference between the time of stopping and starting a circular movement, viz., 91 σ or 49 per cent. The stopping reactions are slower than the starting reactions in this case also for each reactor.

The averages of the two other starting series, Series VI., starting to points, and Series VII., starting to make a geometrical figure, are also, in spite of the complexity of the conditions in these series, for the most part smaller than the averages of the stopping reactions. This rule holds in the case of the individual reactors with but one exception. For C. H. J., Series VII., starting to make geometrical figures was slower than the stopping reactions.

Turning to a comparison of all the starting reactions, viz., Series II., starting a circle; Series IV., starting a vertical movement; Series VI., starting to points; and Series VII., starting to make geometrical figures; it is seen that the last two series, which involve complex preparation, are noticeably longer in most cases than the first two. This result holds for the individual reactors with two exceptions; with C. H. J., starting to points is faster than starting a movement in a circle; and with C. A. C., starting to points is faster than starting a vertical movement. These are but two exceptions out of eighteen cases. It appears, then, that a reaction in which the succeeding movement has a greater number of determining conditions is slower even in starting than a reaction in which the movement has fewer conditions. In starting a movement to a point the reactor has not only to make a movement in a specified direction, as in starting a movement in a circle or along a straight edge, but he has also to stop the movement at a given point. In starting to make a geometrical figure, he has to move through a given distance and then change the direction of the movement. The later stages of the movement are evidently prepared for before the actual turn or pause is made, so that the earlier phases of the reaction are modified in view of the later requirements. Changing the direction of a movement, Series V., has the longest reaction time of all with two individual exceptions. For C. H. J., Series VII., starting to make geometrical figures, is longer, and for C. A. C., Series VII., stopping a vertical movement is longer. This reaction, as will be pointed out in the later analysis, is the most complex of all.

Turning from a consideration of the reaction times to the

character of the records, it will be found convenient to consider separately three parts of the records, namely: first, the parts before the signal for reaction; second, the parts between the signal and the reaction; and, third, the parts after the reaction.

The traced records before the signal are of interest only in the stopping reactions, viz., in Series I. and III., and in the

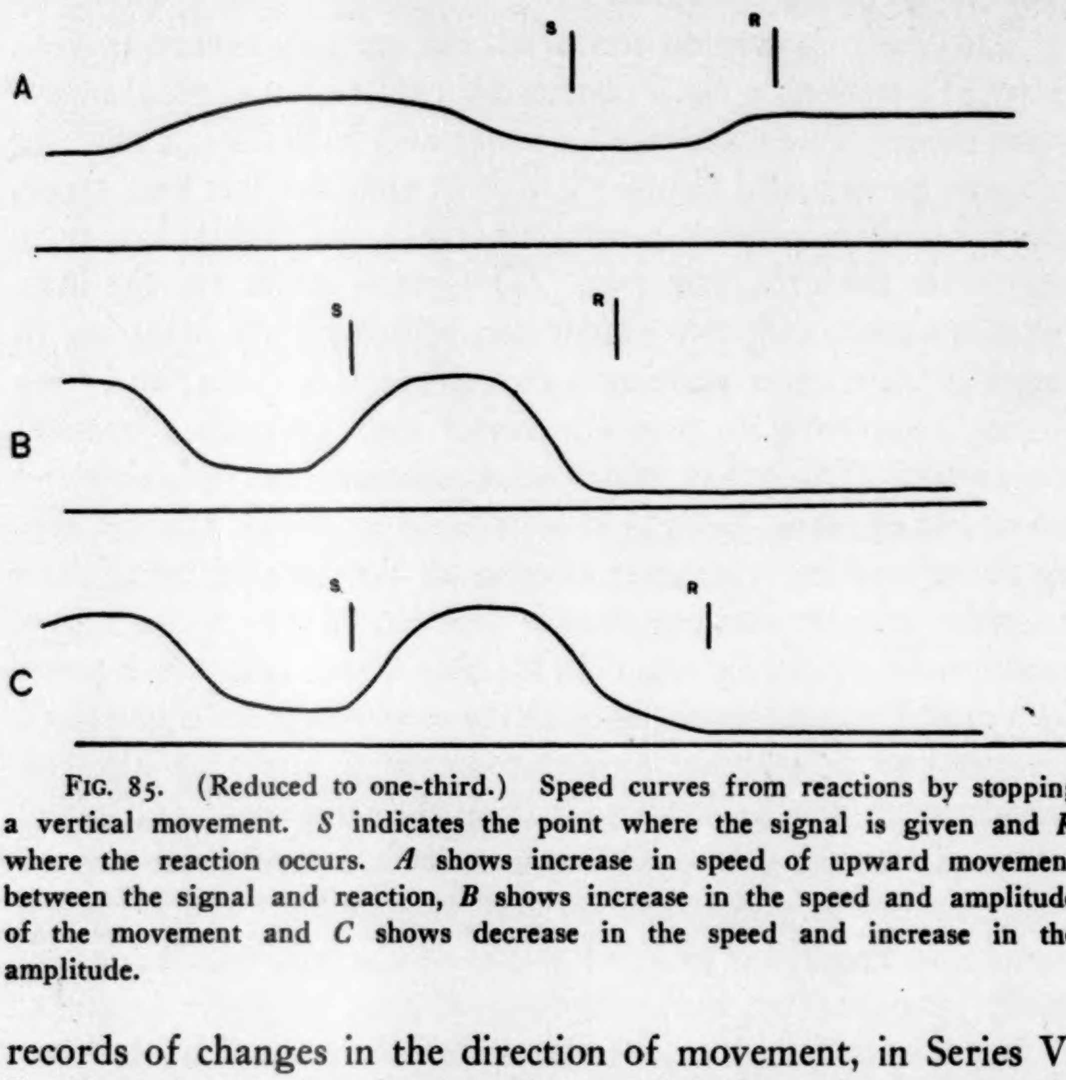


FIG. 85. (Reduced to one-third.) Speed curves from reactions by stopping a vertical movement. *S* indicates the point where the signal is given and *R* where the reaction occurs. *A* shows increase in speed of upward movement between the signal and reaction, *B* shows increase in the speed and amplitude of the movement and *C* shows decrease in the speed and increase in the amplitude.

records of changes in the direction of movement, in Series V. In the other series the traced record before the reaction is merely a straight line. Fig. 85 gives three records from Series III., and Fig. 86 gives five records from Series V. All of these curves are records which can be used in determining the speed of straight line movements. In all cases the speed variations before the signal to react are fairly regular. In the case of vertical movements the speed varies from a maximum at the middle of each stroke to a minimum toward each end, with a final pause at the end of each stroke.

Series I. gave records of circular movements prior to the reaction. In order to ascertain the relative speed of different parts of circular movements, measurements of time required for equal arcs of upward and downward circular movements were made. The results of these measurements are interesting on account of their bearing on writing. Table II. gives the average time of the upward and downward strokes, the difference between them and the number of cases in which the downward strokes and the upward strokes, respectively, were slower. It will be seen that although each person shows a rather uniform relation between the speed of the upward and downward strokes, no two of the subjects of the experiment belong to the same type. Measurements would have to be taken from a large number of subjects in order to determine what is the most common type and what are the causes of the difference between different individuals.

TABLE II.

COMPARISON OF UPWARD AND DOWNWARD STROKES IN MAKING CIRCLES.

Subject.	No. of Cases.	Average Downward Strokes. Sigmas.	Average Upward Strokes. Sigmas.	Difference.	No. of Cases in Which Downward Strokes Were Slower.	No. of Cases in Which Upward Strokes Were Slower.
C. H. J.	15	1,509	1,435	− 74	13	2
F. N. F.	16	1,407	1,395	− 12	11	5
D. J. C.	11	998	1,003	+ 5	5	6
E. H. C.	13	1,409	1,549	+140	1	12

No new observation regarding the changes of rate of movements before the reaction need to be added in view of the report given for Series III. and V.

Turning now to the second part of the traced record, that lying between the signal to react and the final movement of reaction, we are again confined to Series I., III. and V. A number of typical cases are presented in Figs. 85 and 86. In some cases the speed of the movement is increased, as in *A* and *B*, Fig. 85, and *D*, Fig. 86. The record line here falls or rises more abruptly than in the preceding part of the record. Conversely, a larger number of cases show that the rate of a preliminary movement is gradually reduced as the moment of reaction approaches, indicating that the usual method of stopping a movement was to 'slow down' gradually to a stop. This change is seen in *C*, Fig. 85, and *C*, Fig. 86. This would

seem to be the natural method of stopping. Where there is an abrupt acceleration of speed before reaction followed by a sudden stopping, we have a result analogous to the antagonistic reaction noted by Smith in *Mind,* Vol. XII., pp. 47–58, and in Vol. I. (New Series) of these Studies, pp. 141–184.

Changes in the amplitude of the movement can obviously not occur when the circular guide is used, but only with the straight edge, in stopping or changing the direction of a vertical movement, Series III. and V. Such changes between the signal and the reaction are shown in curves *B* and *C,* Fig. 85, and *C,* Fig. 86. Decrease in amplitude is shown by the fact that the upper part of the tracing is lower or the bottom higher than in the preceding part of the line, so that the vertical distance between them is less. Change in amplitude almost always consists in a decrease of the amplitude, indicating that in this respect, as in speed, the movement comes to a stop gradually.

In certain cases of vertical movement there is an increase in the length of the pause at the beginning of the last preliminary movement. There is always a pause, as was noted above, at the top and bottom of each vertical movement. When this pause is lengthened before the last preliminary movement it indicates clearly a conflict of tendencies. The movement is well established and there is a strong tendency to continue it. The signal calls for a stopping of the movement and is only slowly and partially successful in bringing about its result. The lengthening of these pauses between the signal and the reaction occurs chiefly in changing the direction of a movement, Series V., which is evidently a complex form of reaction, as shown by the time given in Table I. Such a lengthening is clearly shown in curves *A, B* and *D,* Fig. 86. This increase in time of the reaction and change in the form of the movement shows that what usually occurred was that the horizontal movement was not continuous with the vertical movement, but the vertical movement was first stopped and then the horizontal movement was begun. There are thirty-three reactions in which the above-mentioned changes in the character of the movement occur between the signal and the

reaction. In some reactions more than one change is present, as, for example, a decrease in the amplitude and a decrease in the speed of the movement.

Significant traced records after the reaction appear chiefly in Series V. The character of the primary line in Series V.,

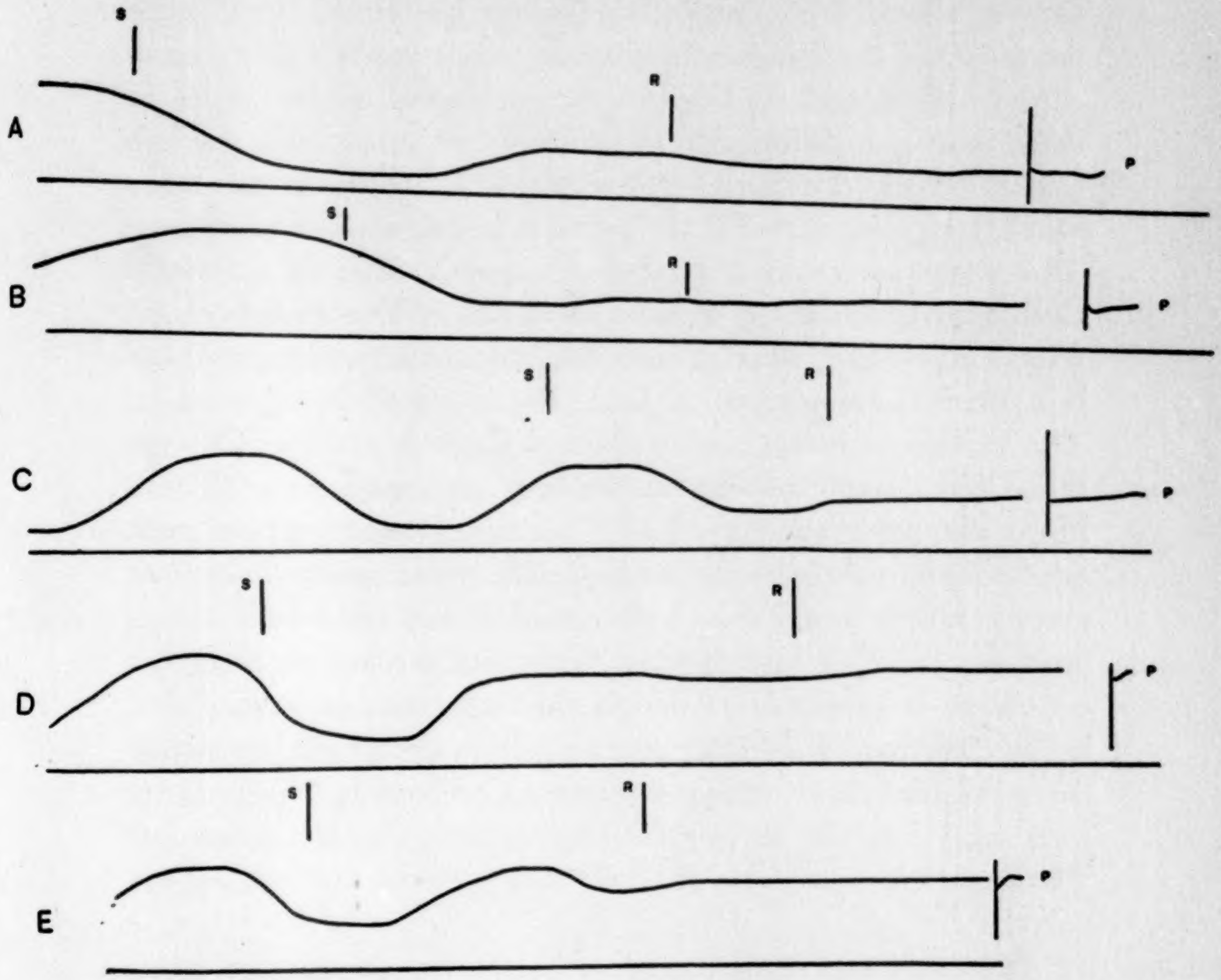


FIG. 86. (Reduced to one-third.) Speed curve from reactions which consisted in changing the direction of a movement, and the corresponding lines as actually drawn on the primary sheet. The latter are indicated by the letter *P*, *P* . . . . *A* shows a decrease in the speed of the vertical movement, a pause before the initiation of the horizontal movement and an inclination of the horizontal movement downward toward the movement just preceding it. *B* shows a pause before the reaction and an inclination of the horizontal movement away from the movement just preceding it. *C* shows a decrease in the speed and amplitude of the vertical movement before the reaction and an unusually straight horizontal primary line. *D* shows marked increase in speed before the reaction and a pronounced pause between the signal and the reaction. *E* shows an inclination of the horizontal movement toward the downward movement just preceding it.

which was made by changing the direction of a movement, is worthy of detailed examination. Examples of these lines are shown in Fig. 86 and are indicated by the letter *P*. These are the primary lines of which the long curves are the secondary lines. The general fact is that the apex of the angle which the horizontal line forms with the vertical line is very much rounded and the first part of the horizontal line is a pronounced curve. *A*, *B* and *E*, Fig. 86, are examples of two types of these lines. In *B* the concave side of the curve faces the last stroke before the horizontal movement. This is the more usual type. In *A* and *E* the curve is in the opposite direction. This form occurs in a number of cases. *C* is an unusually close approximation to a horizontal line. The straight horizontal movement, then, is not attained immediately, but there is a vertical component at first, which disappears gradually. The variations in form show how difficult it is to secure anything like a separate and wholly new movement immediately. Here the established vertical movement tends to pass over gradually into the new movement. In contrast with the earlier cases in which it was shown that preparation for a later movement reaches back into the early stages of a reaction, the influence here is forward. Though the two types of cases differ in the direction of influence, they agree in the general fact that there is a tendency for any single reaction to reflect in its character and rate the surrounding condition in which it occurs. The traced curves show also the transition to the new movement.

We come now to a consideration of the pressure records. A pressure record was taken for each subject, but as it was not convenient to prepare more than one strip of smoked paper for each period, only two or three pressure records on the average were taken with each series. Since the characteristics of the pressure curves were fairly uniform for each kind of reaction, however, and since they were used only for qualitative determinations, this number of records is sufficient as a basis for the description of pressure changes. There are 59 pressure records in all, distributed among the series as follows: Series I., stopping a movement in a circle, 6; Series II., starting a move-

ment in a circle, 7; Series III., stopping a vertical movement, 18; Series IV., starting a vertical movement, 7; Series V., changing the direction of a movement, 6; Series VI., starting to points, 6; Series VII., starting to make geometrical figures, 9.

Fig. 81 shows two typical records, *A* from D. J. C. taken from Series III., stopping a vertical movement; and *B* from C. A. C. taken from Series IV., starting a vertical movement down. The lower line in both records is from the signal marker and the break indicates the signal to react. The second line from the bottom is the time line marking tenths of seconds. The third line is the straight line traced as a base for comparison with the pressure curve. The fourth line is the pressure record. As *B* is the simpler record, we will first analyze that. There first appears before the signal a slightly wavy line, whose crests are from 50 σ to 100 σ apart. The pencil was here held at the fixed point before the reaction with considerable pressure and with slight oscillations in pressure, these oscillations being of a tenth of a second or less in duration. These waves can be satisfactorily explained as due to the succession of nervous impulses necessary to hold the hand in a fixed position. Between the signal and the reaction the waves are less prominent, indicating a change in tension preparatory to the reaction. Just before the reaction shown on the traced record, the pressure begins to increase gradually, and finally, soon after the reaction, which consists in beginning a movement along the straight edge, it increases rapidly by three stages. This marked rise in pressure after the reaction is a feature which appears in nearly all of the reactions. Indeed, the examination of such a record as this gives one a very striking example of the complexity of a reaction. The drawing of a vertical line is evidently accompanied by a series of pressures against the writing surface which must be important in getting the muscular mechanism and the nervous mechanism into operation, but all of which are neglected in any ordinary record of action.

Record *A*, Fig. 81, shows the typical variations in pressure during the making of a series of up and down vertical move-

ments. There are minor variations among different subjects, but the general characteristics for such movements are alike. For the same subject, as will be seen from this record, successive movements of the same kind are accompanied by practically the same pressure variations. In the present case a detailed comparison of the pressure record with the speed record shows that for a straight up and down movement the point of least pressure is about two thirds of the way on the upward stroke. The pressure then increases as the stroke approaches the top, continues to increase, sometimes after a slight decrease, as the stroke comes down and reaches its maximum intensity half to three quarters of the way on the downward stroke. It then decreases and reaches its lowest point again a little past the middle of the upward stroke. A modification of this series which frequently occurs consists of a small secondary increase in pressure at the beginning of each stroke.

The other significant facts shown in record *A*, Fig. 81, are the changes in the pressure variations between the signal and the reaction and the great increase in pressure after the reaction. The signal for reaction comes when the upward stroke is about one third completed. The pressure decreases as usual to its minimum as the stroke goes up, increases as the stroke approaches the top and after a slight decrease increases as the stroke goes down. The pressure changes are as usual up to this point. Here, however, instead of decreasing as the stroke reaches the bottom, it increases rapidly. It remains constant till a short time after the reaction and then increases to about double its previous greatest intensity. This pressure is then maintained. This shows a notable pressure reaction before the primary reaction.

A number of curves showing other examples of pressure changes with some variation are presented in Fig. 87. Record A, from C. A. C., is one of the several cases in which an effect of the warning signal in a change of pressure, without an actual premature reaction, is evident. The fall of the pressure curve below the base line near the right-hand end of the curve shows a partial reaction to the warning signal by a change of pressure, but there was no movement of the pencil across the

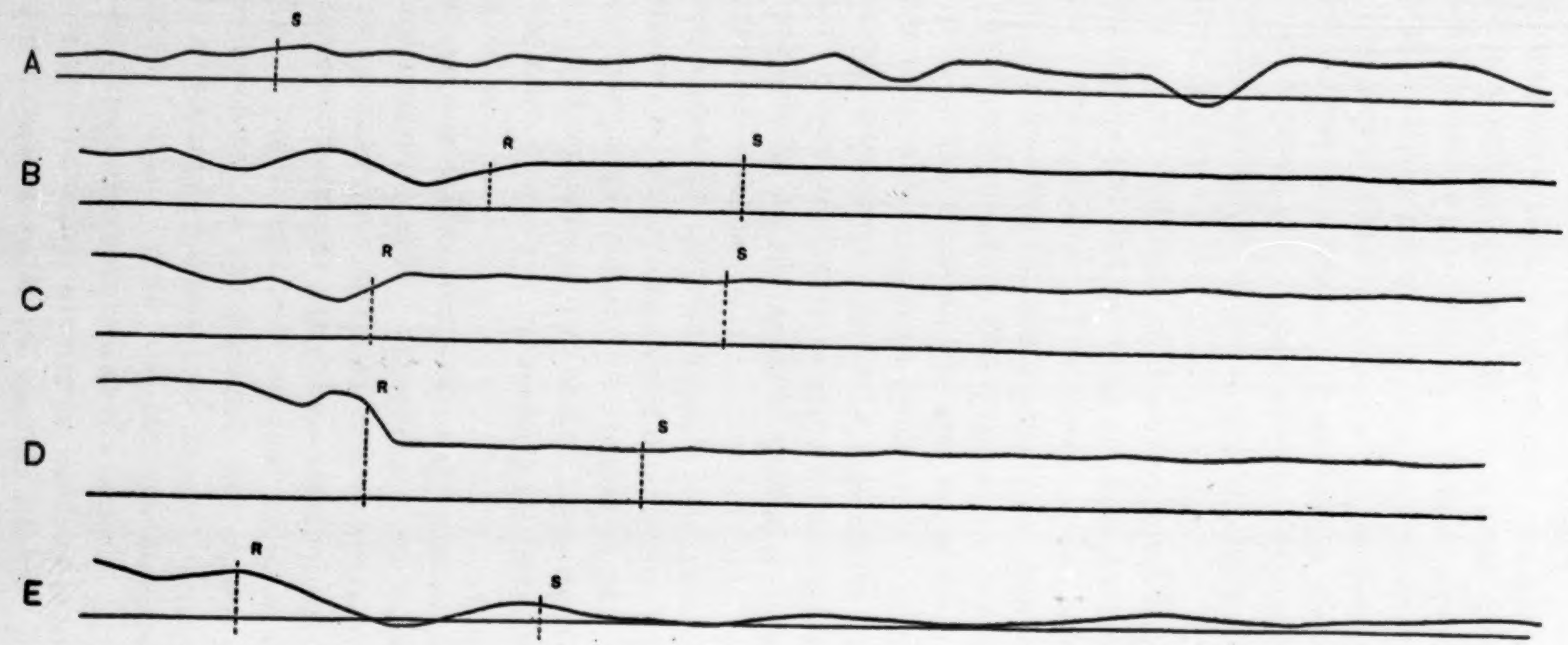


FIG. 87. (Reduced to one-third.) Records of pressure changes during reaction. *A*, no reaction; *B*, starting to points; *C, D,* starting to make a geometrical figure; *E*, stopping a vertical movement.

paper either here or after the reaction signal. In some cases there was also an actual premature reaction to warning, both of pressure and movement across the paper.

Curve *B*, from C. A. C., is from the pressure record of a reaction in Series VI., starting to points. This record shows a slight waviness of the pressure line before the reaction. About 35 σ before the true reaction there is a pronounced decrease in the pressure. After the reaction the pressure continues to decrease, then increases and oscillates while the reaction line is being drawn. Here again the pressure reaction and the reaction proper are seen to be different phases of the total reaction.

C is from E. H. C., in Series VII., starting to make a square. The waviness of the pressure line while the pencil is held at a fixed point before the reaction is here well marked, and continues up to the moment of the reaction. The pressure decreases before the reaction as in *B*, and increases somewhat more after the reaction.

A comparison of the average height of curves *B* and *C* indicates a typical difference in the amount of pressure exerted by different individuals. Pressure also varies somewhat with the same individual at different times.

D is from the same subject and series as *C*. It has the same characteristics until just before the reaction. In this reaction the pressure increases instead of diminishing at the reaction. The increase of pressure which accompanies the drawing of this line begins, as in the previous case, before the reaction. The intensity of pressure after the reaction is greater in this case.

E is from C. H. J., in Series III., stopping a vertical movement. It exhibits the typical pressure variations accompanying the vertical movements. The reaction comes at a point about two thirds down the stroke. The pressure ordinarily rises in this part of the record to its maximum intensity, but in this case the rise in the pressure is directly related to the reaction, as is shown by the fact that it is more than double that of any previous stroke. This is also another example of a pressure change coming before the reaction. After the reac-

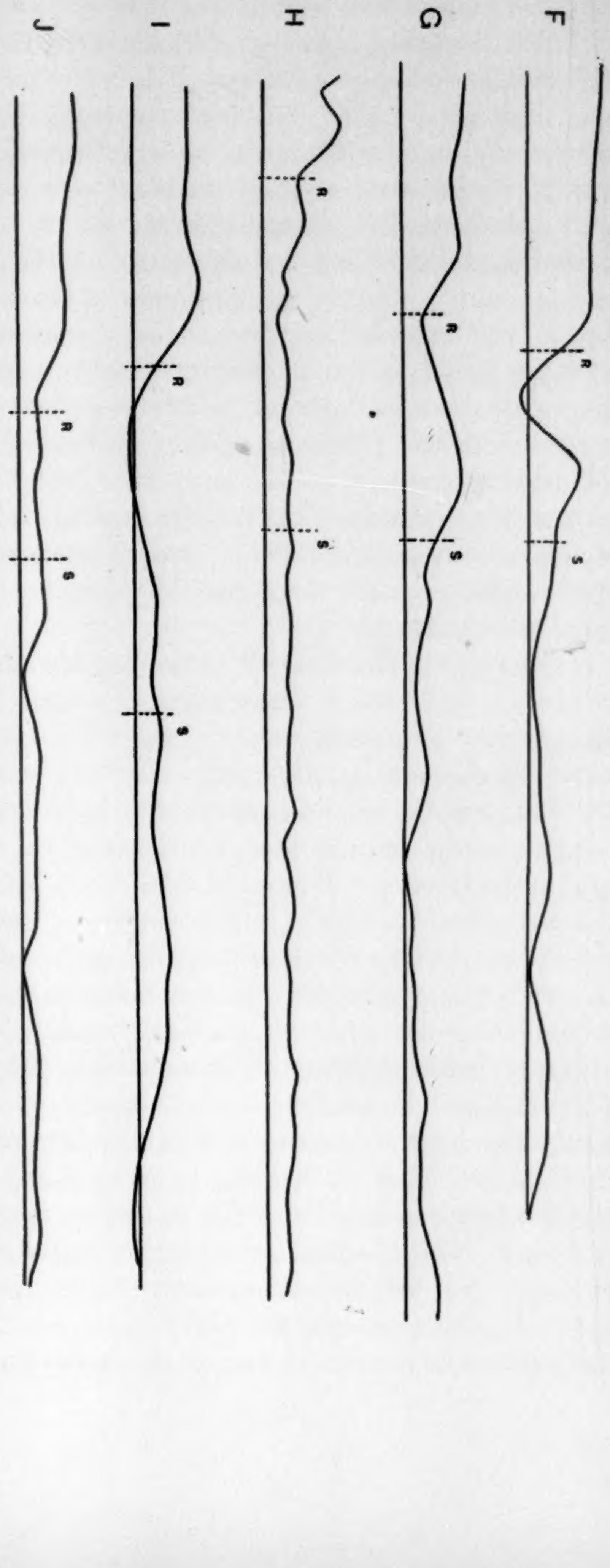


FIG. 88. (Reduced to one-third.) Records of pressure changes during reaction. *F, G,* and *J,* stopping a vertical movement; *H,* changing direction of movement; *I,* stopping circular movement.

tion, the pressure decreases slightly and then increases again as usual. While the pencil is held at a fixed point after the reaction the pressure is not so steady as it is when the pencil is held at a fixed point under ordinary circumstances. It oscillates with a rhythm similar to the pressure variations which accompanied the movement before the reaction.

Fig. 13 shows similar pressure curves.

F, from the same reactor and series as *E*, is typical of certain cases in which a pressure change similar to those which are described above occur before the reaction comes and within 100 σ of the signal to react. The pressure reaction time is accordingly as short as the most rapid forms, while the apparent time measured from the primary movement is slower than the usual reaction.

G is another record from the same reactor and series showing the same sort of pressure change coming about 100 σ after the signal. These records show that there may be a response to a signal in less than 100 σ.

H is from C. A. C., Series V., changing the direction of a movement. This record shows especially regular pressure variations for the preparatory movement. This movement—the vertical movement—stops a little over half way up the stroke. The pressure here increases with a little jerk, producing the curve on the record about two thirds of the way from the signal to the reaction. The hand then pauses before beginning the horizontal movement which constitutes the reaction. Meanwhile the pressure increases rapidly until the reaction. This is another case in which the increase in pressure comes before the movement which it ordinarily accompanies and which constitutes the reaction. The movement which was intended as a horizontal movement is of the second type described above (*E*, Fig. 87), its convex side faces toward the movement last made. That is, it turns back on the last stroke. The pressure increases rapidly as this movement is made.

I is from F. N. F., Series I., stopping a circular movement. The extremely low pressure comes in the fourth quadrant of the circle. In this quadrant the pencil twice left the paper. The reaction occurs about half way on the upward movement,

that is, at the extreme right-hand side of the circle. The pressure increases as usual up to this point and when the pencil ceases to move at the reaction, the pressure continues to increase rapidly till it reaches a high level, which is maintained.

J, from C. H. J., in Series III., stopping a vertical movement, shows the usual rise in pressure after the reaction, and a continued oscillation, suggesting, as in the record *E*, the continuance of the pressure changes which accompany the previous movement.

The characteristics which have been pointed out in these records are typical of the pressure changes accompanying the reactions. For example, out of the twenty-nine records in which the pencil was held at a fixed point before the reaction, fifteen showed a waviness in the pressure curve. Of all the records in which a reaction took place, thirty showed a noticeable change in pressure between the signal and the reaction. In twenty-five cases the pressure increased and in five it decreased. In all cases there is marked change in pressure after the reaction, usually a very pronounced increase. In half of the cases in which a movement is followed by holding the pencil at a fixed point, that is, in eleven out of twenty-two, there is a noticeable oscillation in the pressure line while the pencil is thus held, suggesting a continuation of the previous pressure variations.

Discussion.

In the discussion of the results of this experiment it will be necessary to abandon the distinctions which, for the sake of clearness in description, have been drawn between the various phases of the reaction. No one of the elements, as for example the reaction time, can be considered alone. The difference in the time of various reactions must clearly include some reference to the complex of activity which makes up the reaction. To separate the duration from the other characteristics is to make an arbitrary distinction which obscures rather than aids in the study of the problem.

The point of departure for the explanatory discussion may be taken from the fact first noticed, namely, that the stopping

reactions were slower than the starting reactions. Before generalizing on the results it should perhaps be noted that neither the movements in a straight line nor in a circle, as arranged with the apparatus described, were continuous in a single direction. It is very desirable that measurements of stopping and starting reactions be taken with long movements in a single line. It may be said, however, that the forms of movement used in the experiment are more closely analogous to the great majority of the movements which one makes in every-day life than the simpler form would be. That is, most movements, as in walking, writing, or manipulation of any kind, and also the involuntary activities, involve frequent and more or less regular readjustment in direction. The results here reported would, therefore, apply to these movements.

A movement of the kind under consideration, then, involves not only a continual change in position but also a frequent, and in the case of the circular movement, a continual readjustment of direction. The character of the innervation, the muscular coordination and the direction of application of energy is ever changing. The inhibitory impulse and the type of muscular activity necessary to stop the movement must be different for every change in the movement. Stopping a movement is not a passive affair nor is it a uniform inhibitory process which may be imposed alike on the movement at any point. It is rather an active process, the precise character of which is determined by the particular form of movement to be stopped. It involves a withdrawal of innervation from the muscles which produce the movement and an innervation in turn of the antagonistic muscles. From the point of view either of consciousness or of the physiological mechanism, then, no preparation of a general sort can be made for stopping a movement, such as that involved in the experiment. The attention can not be directed to any point in the movement nor to any specific motor adjustment. No muscles can be innervated nor any nervous path 'set' in preparation for the stopping.

With the starting reaction, however, the case is different. The process of preparation for a reaction by a partial innervation of the muscles which produce the movement and a 'set'

of the nervous path is too familiar to need more than mention. It is easy to understand from the greater complexity of the stopping reactions and the fact that they permit of no preparation why they require more time than the starting reactions.

The qualitative records of these reactions bear out this statement of the difference between the starting and stopping reactions. The first response to the signal in stopping a movement is a diffuse spreading of the innervation, rather than a precise reaction along well-defined paths. This causes in the majority of cases at the same time a decrease in the speed and amplitude of the movement which is being made and an increase in the pressure exerted. In contrast to this, in the starting reactions a decrease in pressure often came at first, showing that the innervation is applied directly to the muscles involved in the precise reactions. When the movement was stopped the energy was not withdrawn but was transferred by an elaborate readjustment to another set of muscles.

If the explanation offered of the difference in the time of stopping and starting a movement is correct, we should expect that changing the direction of a movement would also be slow, for changing the direction of a movement consists in some cases, as was pointed out in the description of the records, in first stopping the movement and then beginning a new one in a different direction. The complete process already described as characteristic of stopping a movement had to take place and an additional activity had to be inaugurated to produce the new line. The case is further complicated by the fact that the particular activity which is required to produce this new movement is dependent upon the point in the earlier movement at which reaction happens to take place. Sometimes, it is true, the reactor seems to be able to eliminate the stopping process to a certain extent, and make the horizontal movement continuous with the vertical, without a pause; but the effort is usually only partly successful, as shown by the fact that the new movement starts not horizontally, but at an acute angle from the vertical line, indicating that the innervation into the old channels was not entirely inhibited before the new impulse began to act. In any case this process would be as complex as that of stopping

a movement, the coordination producing the new movement being substituted for the coordination which produced the inhibition of the movement.

The results in all these cases of movements turned into a new direction should be recognized as results with reactors who were not especially expert in the particular kind of movement here undertaken. If the explanations are to be applied to long-practiced activities, such as those of writing, it should be recognized that the succession of innervations is much less delayed after practice. There is even then a necessity of stopping the old reaction and beginning a new reaction, but the well-trained coordinations show little of the diffuse period. Indeed there were some cases of reaction by changing the direction of a movement in which the diffuse period was much shorter than usual, but it was nearly always long enough to indicate that the reaction was more complex than a simple stopping reaction. Among the results reported in this paper the descriptions given of the transitions from one part of a circle to another, or from an upward line to a downward line are better examples of well-trained and fully prepared transitions in movement.

The greater length of the reactions in drawing a line to a point or in making a geometrical figure would seem to be susceptible of a similar explanation. In these cases the initial movement was definite enough, but the attention was divided between the initial movement and the later stopping of the movement. The movement was not only to be made, it was also to be stopped or its direction changed at a certain place. This fact must have resulted not only in the innervation of the muscles employed in the initial movement, but also in the partial innervation of the muscles used in the subsequent stopping or change in direction, and this must have interfered with the rapidity of the reaction.

The analysis of movements undertaken in this investigation shows that there are a great variety of readjustments which are not fully and explicitly recognized by the reactor. This can be brought out by reporting certain introspections which the reactors gave during the series. For example, one reactor introspected the vertical starting movements,

especially the upward movements, as slower than the stopping movements. On the contrary, the starting movements were the faster and of these the upward movements were the faster. Again a reaction was sometimes introspected as slow when the reaction itself was fast, but the movement following the reaction was slow. One reactor, for example, said that, in Series III., stopping a vertical movement, he always stopped before the stroke was finished which he was making when the signal came, provided the signal came near the beginning of the stroke. If the signal came past the first part of the stroke he said he stopped within the next stroke. As a matter of fact he in no case stopped before he had made two strokes after the signal.

Again, the pressure changes were not recognized as pressure changes. Though they were constantly present the reactors were for the most part wholly unaware of them; they existed for the reactor's consciousness not as pressure changes but as changes in the position and character of the movement.

This confusion of the factors involved in movement is explained if we regard the function of consciousness as not primarily to mirror the separate elements of movement, but to grasp it as a unit, though a progressively changing one.

The reactor was not conscious of changes in the speed and amplitude of movement, or of the changes in intensity of pressure which have been described as occurring between the signal and the reaction. These were merged for consciousness into the perception of the reaction. The changes in speed and amplitude and the final stopping made up the change of balance between rest and motion which constituted the reaction, but only the total change and not the gradations from motion to rest were apprehended.

The results of this investigation emphasize the unity of a reaction process and emphasize further the complete parallelism between the conscious attitude as a whole to the reaction complex as a whole, while showing clearly that consciousness does not reflect in detail the factors of the reaction.

REACTIONS TO EQUAL WEIGHTS OF UNEQUAL SIZE.

By HERBERT N. LOOMIS, B.S.,

Instructor in the State Normal School, New Britain, Conn.

This paper describes a method of recording the movements which are executed in lifting two boxes of equal weight but unequal size. It was found from records thus taken that the small box is usually raised later than the large box and that less energy is expended in lifting the small box than in lifting the large one. Examples of the records are shown and the results are discussed in detail.

The illusion which results when an observer lifts two blocks of unequal size, but equal objective weight, has been the subject of much investigation. So far as the writer is able to discover, however, no attempt has been made to secure direct records of the muscular reactions accompanying the illusion. With this end in view, a large number of records were taken with thirty-six reactors, most of whom were not familiar with the illusion or its explanation. The total number of records referred to in the present paper is about 400.

The apparatus employed in securing records is represented in Fig. 89, a large box *A*, 22.7 x 22.7 x 22.4 cm. outside measurement, weighing 352 grams rested on the platform *P*. Beside box *A* was a shelf *S* on which rested a small box *B*. The shelf was just high enough to bring the top of the small box *B* to the same level as the top of the large box *A*. Box *B* was decidedly smaller than box *A*, being only 3.7 x 3.8 x 4 cm., yet was weighted so as to equal in weight the large box *A;* it weighed therefore 352 grams. From the center of crosspieces in the bottoms of the boxes, linen threads *CC* passed down through holes in the platform, over pulleys *YY*, to small weights not shown in the figure, but attached to the threads at *W* and *W*. The weights were each 57 grams and served to keep the thread under tension when the boxes were placed on the platform. Between the pulleys *YY*, the threads *CC* were attached to the arms of levers *LL*. Boxes *A* and *B* could

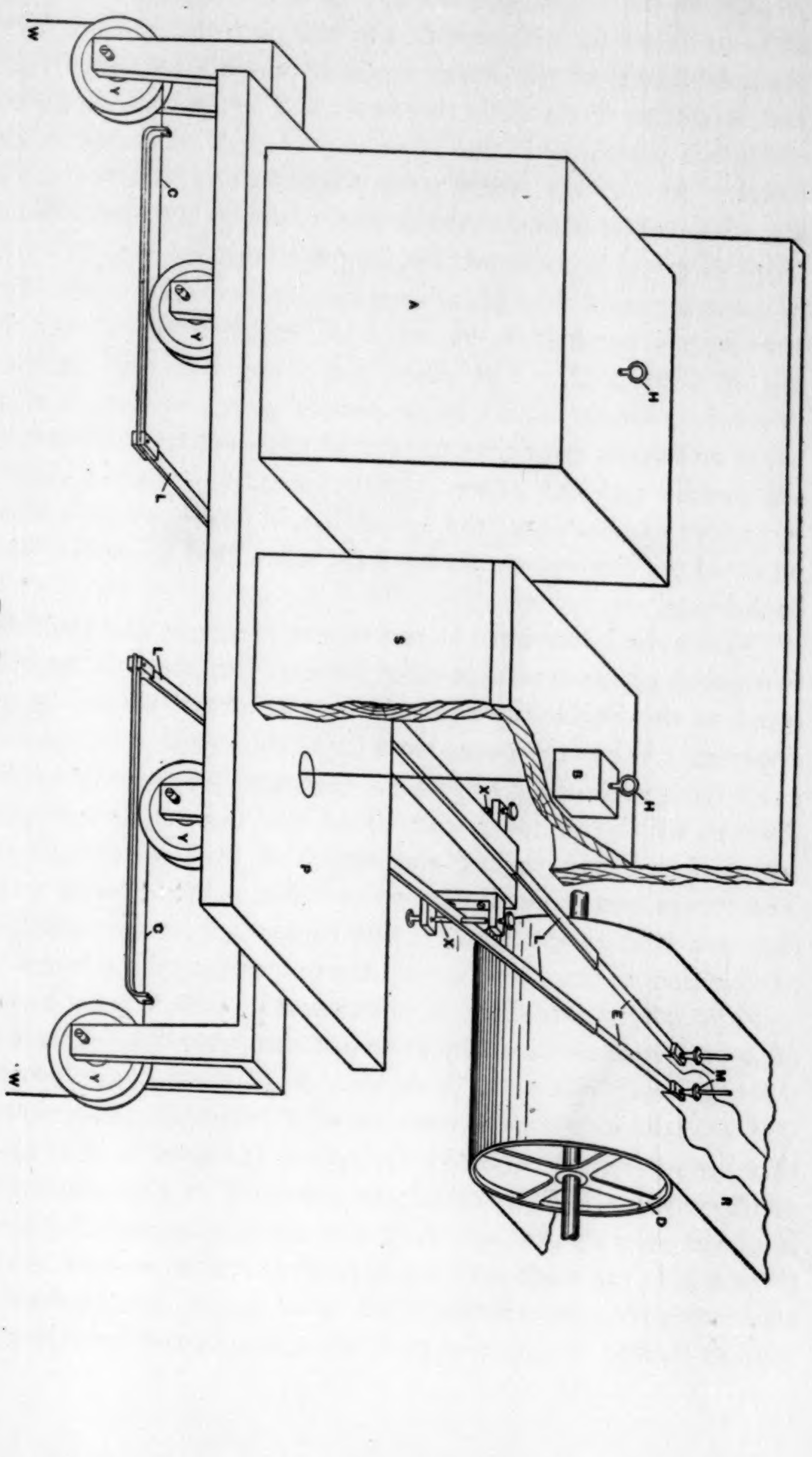


FIG. 89.

be interchanged quickly because of the simple fastening device in each of the boxes, and the fact that the shelf *S* was made so as to be set up on either end of the platform. This interchangeableness of the boxes made it possible to secure right and left-hand trials with the boxes. The levers *LL* passed under the platform *P* and appeared beyond, as shown in the figure. At *XX* the levers were pivoted so as to move in the same horizontal plane. At the extremities of the levers elastic strips of metal *E* continued the length of the levers to *M*. At *M* pencils passed through adjustable clutches. The pencil tips bore on a paper belt *R*, 15 cm. wide, which traveled over the top of a drum *D*. The elastic metal strips *E* were inserted to secure constant contact of the pencils' points with the moving paper and at the same time to prevent excessive friction between the pencils and the paper. Each box was provided with a screw eye *HH*, so that the subject could easily grasp it when he lifted the box and would have the same kind of contact with both boxes.

When the boxes were at rest on the platform and shelf the two pencil points traced parallel lines on the paper *R*, as indicated at the beginning and end of the record shown in the drawing. When the boxes were lifted the pencil points moved away from each other and traced curves which showed the distance to which the boxes were lifted, and the exact moment at which they began to rise and at which they were replaced. The curves also show all vertical movements of the boxes while they are held in the hand. The compound levers prevented any binding of the string during the movement of the levers.

The subjects stood facing the boxes *A* and *B*. By means of a pasteboard screen not shown in the figure the levers and moving paper ribbon were hidden from view. The subject was brought into such a position with reference to the boxes that his arms were extended during the lifting in an easy horizontal position. The subject was instructed to grasp the boxes *A* and *B* by the screw eyes *HH* between forefinger and thumb, in as nearly the same manner as possible; to raise them in any way preferred; to estimate their relative weight and then to replace them. In the majority of cases, the subject reported

after the trial his experience with the boxes, in such terms as the following: "The smaller is twice as heavy as the larger one." "They seem this time more nearly alike." "They are coming nearer together." "The difference between them is increasing; the smaller is about six times as heavy as the larger one now." "They are nothing alike, but I can't tell how much heavier one is than the other."

In Fig. 90 is shown a record taken from the series of subjects No. 21. The arrow points in the direction in which the

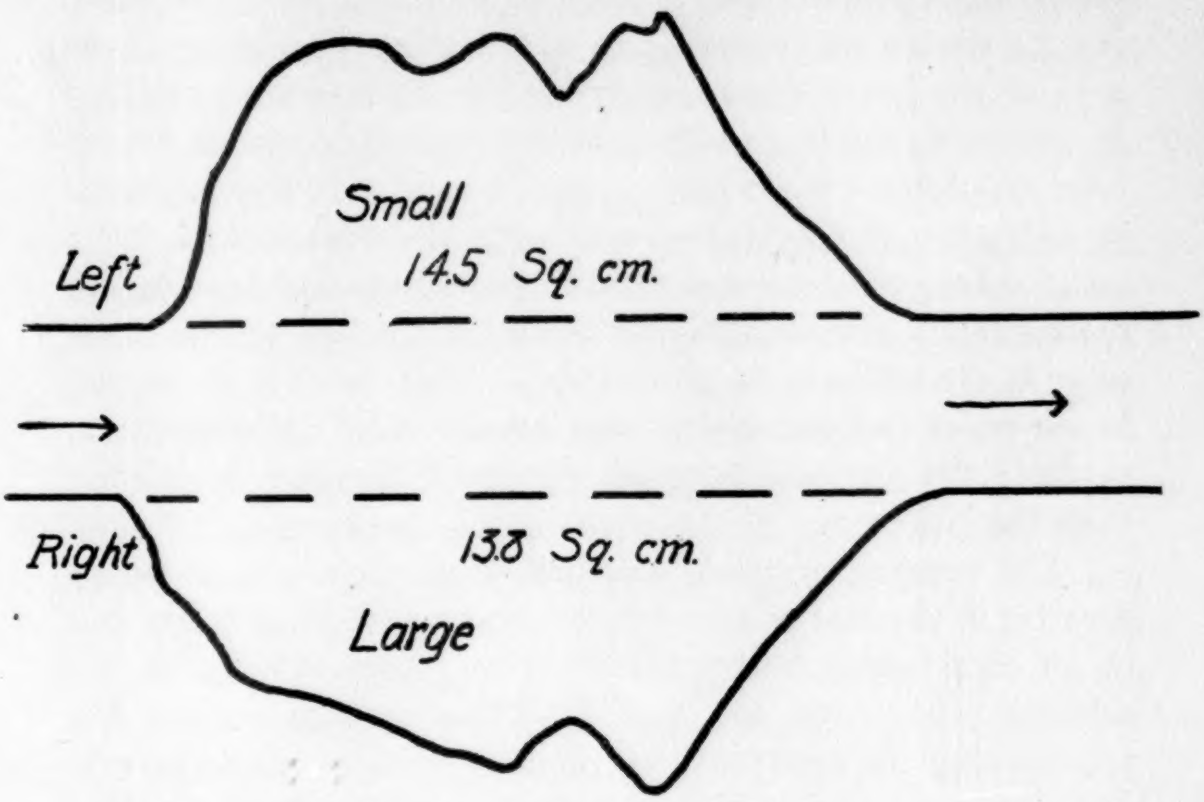


FIG. 90.

record was made. The words 'right' and 'left' indicate right and left-hand records respectively. 'Small' and 'large' refer to boxes *B* and *A*. In the record it is clearly evident that the large box was first raised because the record for this box leaves the horizontal before the record for the small box. Furthermore, it will be seen that there is some difference between the amount of lifting in the two cases. In order to secure a quantitative basis for comparison in this matter, the following method has been used. Base lines, shown by the dotted lines in the figure, were drawn from the point where the

box was first disturbed, as shown by the lines losing their evenness and horizontal direction, to the point where the boxes were replaced, as shown by the fact that the lines again assumed an even and horizontal character. By means of a planimeter the areas enclosed by the base lines and the curves of the records were measured. The enclosed areas are in direct proportion to the amount of energy expended by the subject in lifting the boxes while judging their weight. In the case shown in Fig. 90, the amount of muscular energy expended while judging the small box is proportional to the area of the upper curve which is 14.5 square centimeters. In like manner 13.8 sq. cm., the area of the lower curve, represents the expenditure of energy in estimating the large box. Allowing 100% to stand for the total expenditure while judging both boxes, 51% was expended in estimating the small box and 49% in estimating the large box. Many of the curves show a much greater difference and most show a greater area for the large box, as will be made clear in the tables to be given later. This curve is the second in the series and the subject was influenced by the observation made in the first test in which the small box seemed heavier than the large box.

The number of trials obtained from each subject varied greatly; in the case of two subjects going as high as thirty and in no case falling below three. The great majority of the subjects made from five to seven trials in each series. On approaching the apparatus for the first series of trials the subject was in nearly every instance unacquainted with the illusion. He was given no information about the experiment, but was merely told to lift the boxes and determine, if possible, their relative weights. Furthermore, he was asked to give his impressions while making the trial. In not more than two cases was the illusion known to the subject, or explained to him before he began. The results of these subjects were not essentially different from those of the subjects unacquainted with the illusion and consequently they are not separately treated. Sixteen of the thirty-six subjects gave on later dates a second series of trials under conditions similar to those of the first series except that they had in the second series the benefit of such experience as they gained in the first series.

In both the first and second series a number of cases were introduced in which the subject after lifting the boxes in the natural way with open eyes, lifted the boxes from three to sixteen times in succession with eyes closed. During these series, which will be designated as closed-eye series, the subjects did not look at the boxes at all. Whatever illusion they experienced depended upon the memory which they had of the earlier visual perception of the boxes. Twenty-one such closed-eye series were obtained.

In certain cases the apparatus was set up in such a way as to present the large box to the right hand, in others so as to present the small box to the right hand. A general survey of the records does not show any characteristic differences for these cases.

Thirty-one of the thirty-six subjects, at their first trial, pronounced the small box the heavier; three said the boxes were equal; one regarded the large box as heavier; one was suspicious that by some magnetic or electrical contrivance the weights of the boxes were made to vary while in his grasp.

Turning now to the way in which the boxes were raised, or as we shall hereafter call it, the mode of attack, it is perfectly clear that in the great majority of cases the large box was

TABLE I.

A.

Trials.	1	2	3	4	5	6	7
Large.	33	28	24	20	17	10	4
Small.	1	5	7	4	4	4	2
Equal.	2	3	5	5	7	5	3

B.

Trials.	1	2	3	4	5	6
Large.	10	10	11	7	7	4
Small.	2	0	0	2	2	1
Equal.	1	3	2	4	3	3

C.

Trials.	1	2	3	4	5
Large.	9	11	11	8	8
Small.	4	4	2	2	0
Equal.	3	1	3	3	4

raised before the small. This is shown in the curve reproduced in Fig. 90 and in the first curve in Fig. 92. Table I. shows the total number of cases for all of the subjects, in which each of the boxes was first attacked, and the number of cases in which no measurable difference in the time of attacks appeared. The quantities in the horizontal columns marked 'Large' show the number of cases in which the large box was first attacked. 'Small' indicates in like manner the number of first attacks of the small box, and 'equal' indicates simultaneous attack. The table shows the distribution of 'first attacks' in successive trials. Thus, under 1 the results are shown for the first time each of the subjects took up the boxes. The quantities under 2 show the modes of attack in the second trial, and so on. The total number in each vertical column shows how many subjects made that trial. Thus, in Table I., *A,* thirty-six subjects made three trials, twenty-nine made four trials, twenty-eight made five trials, and so on. The three parts of Table I. show the results for the first series of trials (*A*), for the second series (*B*), and for the tests with closed eyes whether taken with the first series or second (*C*).

The same results are presented in Table II. in percentages. Thus thirty-three cases of first attacks of the large box in the

TABLE II.

A.

Trials.	1	2	3	4	5	6	7
Large.	92	78	67	69	61	53	45
Small.	3	14	19	14	14	21	22
Equal.	5	8	14	17	25	26	33

B.

Trials.	1	2	3	4	5	6
Large.	77	77	85	54	58	50
Small.	15	0	0	15	17	13
Equal.	8	23	15	31	25	37

C.

Trials.	1	2	3	4	5
Large.	56	69	69	62	67
Small.	25	25	12	15	0
Equal.	19	6	19	23	33

first series are 92% of the total number of such cases obtained from all subjects. The percentage tables are used for the curves in Fig. 91.

Before turning to a discussion of these tables and curves,

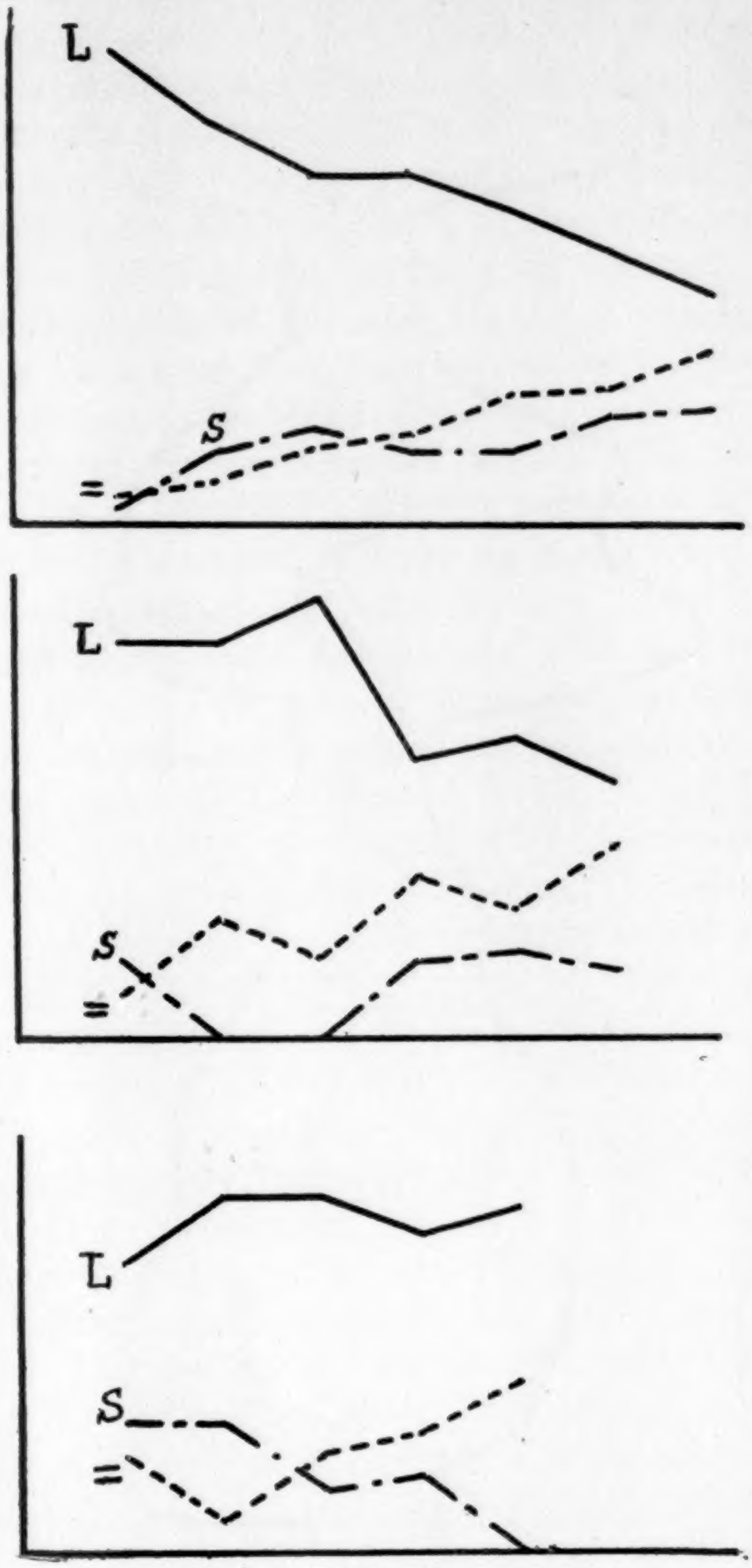


FIG. 91.

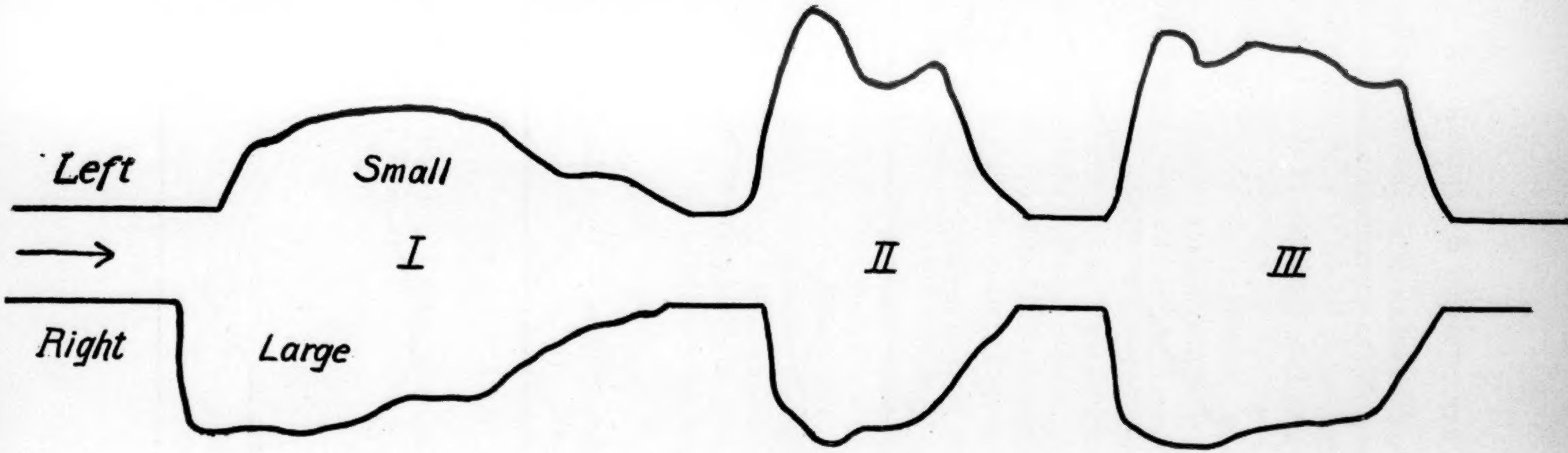


Fig. 92.

it may be well to present a series of records which show very strikingly the three modes of attack. Such a series of records is reproduced in Fig. 92. These are records of the first, second and third trials in the first series of subject 29. It is to be noted that after a first trial which gives very clearly the typical mode of attack of the large box first, the second and third trials show a readjustment in the mode of the attack. This readjustment results in the second trial in a vigorous attack upon the small box which was much behind in the first trial. There can be little doubt that the motive of this readjustment is to be sought in the experience gained in the first test. The subject is no longer dependent upon his visual experience alone. He has, in the second trial, the results of the first test in which he found the small box heavier than the large box. He consequently attacks the box which he believes to be heavier with greater vigor. The third trial shows a tendency, as contrasted with the first and second, to make the attack less a matter of previous adjustment. The boxes are now picked up together and judged afterwards. Every record after the first is a complex. In spite of this, the table shows that the large box continued throughout to be in general the box first attacked.

Returning to the discussion of Tables I. and II. and the curves in Fig. 91, it will be seen that the percentage of attacks on the large box is throughout the highest. It falls off steadily, however, in the successive trials under the influences discussed in the last paragraph. The number of first attacks on the small box changes more irregularly in the successive trials. There is a general tendency towards more frequent first attacks of this box, but the irregular curve shows clearly that this tendency is complicated by other factors. Especially notable is the fact that in the second column of Table *A* there is an enormous increase in the percentage of small box attacks. The influence of the experience obtained in the first test is thus clearly evidenced. The simultaneous attacking of both boxes increases steadily throughout the trials. This tendency to equalize is evidence of a more deliberate and well balanced preparation for the judgment. In the second series of trials reported in *B* and secured from certain of the subjects reported in the first

series on days subsequent to that of the first series, the same general tendency is displayed in the curves for the large box, and in the curve of equal attack. The curve for the small box displays even greater irregularity than in the first series. This last-mentioned curve begins at 15% and instead of rising to a higher point as in the first series, it drops immediately to zero and remains at zero until the fourth trial when it rises to 15%. In the trials in which the eyes were closed (Closed-eye Series), the striking fact is that the directions of the large and small box curves are reversed in direction from the similar curves in the first and second series, yet the curve of equal attacks has the same general upward movement, though less regular.

Turning from the question of the time of attack to the areas of the curves, it was found that on the average the areas of the curves for the small box were less than the areas of the

TABLE III.

Trials.		1	2	3	4	5	6
A	Small.	10.9	9.1	8.6	7.0	8.6	7.6
	Large.	10.4	10.4	11.3	8.0	8.4	8.4
B	Small.	13.0	24.9	78.4	27.5	28.2	27.0
	Large.	16.5	27.3	85.4	25.9	37.6	36.9
C	Small.	7.3	25.1	12.2	13.0	26.3	9.9
	Large.	6.4	24.0	12.6	13.1	17.5	11.9
D	Small.	8.7	9.5	11.3	6.1	6.6	9.8
	Large.	5.4	11.8	17.9	8.5	16.8	10.0
E	Small.	25.9	3.2	7.1	4.6	14.0	10.4
	Large.	33.9	13.6	11.1	9.1	25.0	14.9

curves for the large box. Table III. shows the record in detail for five subjects, each of whom made six trials. The quantities are square centimeters. It will be seen from this table that there are many exceptions to the general rule, frequent cases appearing in which the area is greatest for the small box. Attention should not be distracted by these exceptions from the general result which is unequivocal. It should be remembered that the individual cases are complicated series of adjustments rather than single acts. The curves are often spread out over distances of ten centimeters or more and are very irregular in form. Indeed, the curves vary so much in form and area that it was found to be advantageous to reduce all areas to a percentage basis, as indicated in connection with

Fig. 90. The areas of the small box and large box curves for a given subject in a given trial were added together and treated as 100%. The area of each curve was then expressed as a part of the total 100%. The percentages thus obtained were averaged for the thirty-six subjects with the results reported in the horizontal columns marked 'Per cent. large' and 'Per cent. small' in Table IV. Subtracting the percentages for the

TABLE IV.

FIRST SERIES.

A.

Trials.	1	2	3	4	5	6
Per cent. small.	44	44	43	46	45	47
Per cent. large.	56	56	57	54	55	53
Difference.	12	12	14	8	10	6

SECOND SERIES.

B.

Per cent. small.	46	47	48	47	47	47
Per cent. large.	54	53	52	53	53	53
Difference.	8	6	4	6	6	6

THIRD SERIES (EYES CLOSED).

C.

Per cent. small.	45	42	45	43	47	43
Per cent. large.	55	58	55	57	53	57
Difference.	10	16	10	14	6	14

small box from those of the large box, we obtain results which are reported in the column marked 'Difference.' From these differences is plotted the curve shown in Fig. 93. It will be noted that in every case the average area for the large box is greater than that for the small box. It will be noted further that this greater area for the large box steadily decreases throughout the first series and that it is in general lower in the second series than in the first. As in the matter of 'attack,' the closed-eye series is irregular as might be expected from the complex conditions under which these tests were taken and their irregular distribution through the first and second day's trials.

In addition to the order of attack and area, the curves show many characteristics which invite further attention. The number of curves from each subject is relatively small, however,

and it seems desirable to obtain longer series with each subject before attempting to formulate results regarding the character of the curves. In spite of the small number of records from each of the subjects, it was evident in a number of cases that the subject showed an individual mode of reaction to the boxes. This individual mode of reaction showed variations in successive trials, but tended to recur even in the short series taken.

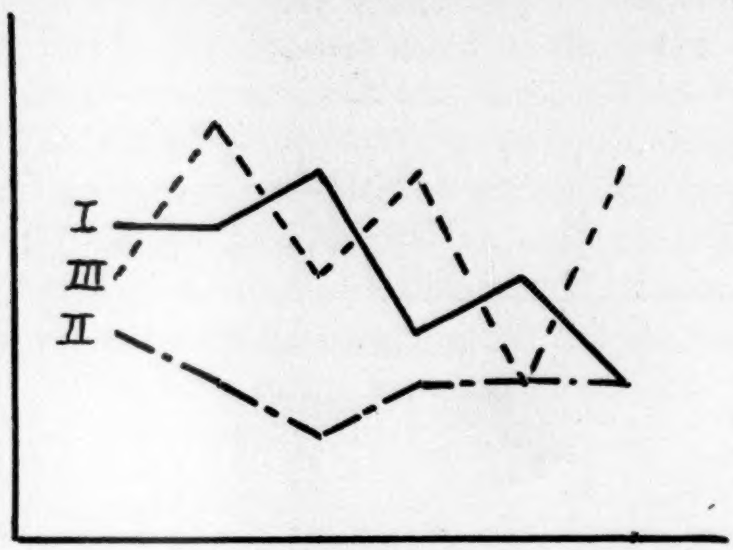


FIG. 93.

There were also differences between the reactions to the large and small boxes; the two boxes being in many cases lifted in typically different ways. There was, however, such a relationship between the two curves in a given trial that when one curve varied from that of the preceding trial, an accompanying change of some kind appeared in the parallel record for the other box. More records are being collected and a subsequent report will deal with the form of the curves.

All of the results obtained go to show that a subject has much greater muscular tension in the hand which lifts the large box than in the hand which lifts the small box. This greater muscular tension is the direct expression of an organized habit of response to familiar visual objects. So far as any subject has had experience with boxes made of like material, he has found in general, that the larger the box the more the energy required to lift it. This organized tendency of expression is an essential part of the perceptual process. The muscular

tension is not due to any voluntary effort, but is the motor phase of a total sensory-motor adjustment which is the perceptual process. The naive sensory-motor adjustment is disturbed, as shown by the tables even in the second test. After the first attack in the first series, when the great muscular effort expended on the large box resulted in the striking experience that the large box seemed too light, there began a shifting of attention and at the same time a modification of the muscular adjustment. That is, the subject failing to realize the expected resistance from the small and large boxes, began to modify at once his perceptual experience and his muscular tension. This tendency to readjust shows itself, as pointed out above, in a marked increase in the number of cases in which the small box is lifted first. Fig. 92 shows the character of such a readjustment very clearly. The most striking evidence of the tendency to readjust the whole muscular reaction appears in the facts shown in all the tables and curves, that the cases of simultaneous attack increase steadily from trial to trial and the difference in the areas of the curves for the large and small boxes gradually tends to disappear. In individual cases the corrective tendencies are so strong that the small box is frequently attacked for one or more trials more vigorously than the large box.

The apparent disappearance of distinctive motor adjustments to the two boxes in the course of the experiments is not to be misunderstood as showing an independence of the motor adjustment from the perceptual experience. For, in the first place, many of the subjects gave the judgment equality or even less weight for the small box in the course of the series. Above all, every subject had after the first trial, as has been repeatedly pointed out, the direct testimony of his own experience that the small was not lighter than the large box. When any subject began in the second, and succeeding trials, to pick up the boxes, his perceptual process was influenced to some extent by his experience in the first trial. The fundamental habit of reaction to the two boxes was not entirely overcome, however, as is shown by the general fact that on the average greater energy was expended on the large box throughout the whole series.

The irregularities in form of movement which appear in the second and in subsequent trials are consequently to be related directly to the conflict in perceptual experience between the natural tendency to react differently to the two boxes and the experience acquired in previous trials. The intimate relation between perception and motor adjustment is consequently clearly shown by all the results.

STUDIES IN PERCEPTUAL DEVELOPMENT.

By CHARLES H. JUDD

AND DONALD J. COWLING, M.A.,

Professor of Philosophy, Baker University.

This paper reports the development shown by a number of subjects in the course of a series of tests in which they attempted to reproduce a simple figure which had been shown to them for ten seconds. The reproductions were made under varying conditions; sometimes with the eyes closed, sometimes with the result covered so that only the hand movement used in drawing could be seen, sometimes with both the movement and results of the drawing clearly visible. It is shown by a comparison of these results that the recognition of the figure is gradual, some subjects beginning at the beginning of the figure and working it out in detail, others beginning at other points in the figure. It is shown that the greatest amount of error is in the middle of the figure. It is shown that there is a difference in the rate of mastery of the size and relative position of the lines. It is shown that in certain cases parts of the figure may improve for a time, and the same parts may later be partially or completely overlooked. The series of tests is available for a demonstration of the improvement which arises from practice in a very short interval.

The purpose and character of the tests to be reported in this paper can best be made clear by a brief consideration of certain of the different types of mental development included under the general term, learning. It is evident that the process of learning the meaning of a word is very different in character from the process of learning to use a tool. Learning to repeat a list of names is essentially different in its elements and development from learning to draw. These illustrations show that the student of psychology must devote himself to a great variety of different investigations if he would make an exhaustive experimental study of learning processes. Thus, it must be recognized that the results gained from an investigation of some habit of manual dexterity are not forthwith applicable to other spheres of learning. Without attempting to formulate any complete classification of learning processes it may be said that the present tests deal with the progressive mastery of certain simple percepts. The motor processes which were of

necessity involved in securing the results did not change appreciably in the course of the tests. The ideas which the subjects had were, indeed, considered and recorded, but they were not the matters of chief interest to either the subjects or the experimenters and they did not undergo any significant modification in the course of the tests. The memory which was involved in carrying out the experiment was not variable, except as it varies in successive stages of any perceptual process.

The outcome of the investigation must serve as the justification for the selection of such a problem, but it will not be out of place to state at the outset some of the considerations which prompted the writers to take up the study of this special phase of learning. In the first place, little or no experimental work has been done in this special field. Many forms of motor practice have been examined and many complex processes such as those involved in remembering ideas and mastering more or less complex systems of ideas have also been investigated. Percepts have, indeed, been thoroughly examined by purely analytical methods, but the application of genetic methods to this type of experience has been relatively uncommon. In the second place, the writers were convinced from a review of the few results which have been secured through a genetic examination of percepts, that the theory of perception itself, as well as the theory of the learning process, would be advanced by an examination of the changes due to increased familiarity with simple percepts. The genetic method is advantageous as a means of analysis, for whenever a change appears in conscious experience as a result of practice, the elements of the experience are sure to undergo a rearrangement of such a character that they will be more easily discovered than a relatively static experience which is undergoing no marked development. In the third place, there was a practical motive in the present investigation. It is very desirable that a number of simple tests be devised which shall furnish the student in a reasonably short period with definite concrete material on which he may base some preliminary study of mental development. A single laboratory period is not adequate time in which to secure a significant series of improvements in

most habits. Something can be done in the line of motor development if very crude forms of movement are taken and the results are reduced to a type of record which makes possible exact measurements. But even under the most favorable conditions changes in motor processes are not very marked in a single laboratory exercise. Nor are the experiments with memory or association especially favorable single exercises. The tests with percepts, on the other hand, offer a very favorable opportunity for the study of some of the most typical forms of mental development within the compass of a single laboratory period.

The method of these tests was as follows. A simple figure made up of straight and curved lines was exposed to the subject's view for a period of ten seconds and then covered up. The subject was required immediately to draw the figure as he had recognized it. The figure was then exposed for another ten seconds and the subject made another drawing. This continued for ten or more times with the same figure. Three different types of conditions were imposed upon the subject during the drawing. First, he was required immediately after the pattern was covered to close his eyes and draw the reproduction without seeing his movements or the drawing which he produced. Second, he was allowed to see his movements, but not the drawing which he produced. This was accomplished by requiring him to trace with a dull metallic point on carbon paper. The carbon paper was, before the beginning of the experiment, defaced by a great number of lines, so that the special marks made in the tracing of the figure were not distinguishable. The figure traced on the blank paper under the carbon paper served as a perfectly clear record of the movement, but this figure was not seen by the subject himself. Third, the subject was allowed to see both movement and resulting drawing. The three cases will be designated in all tables and references as follows: *S* (shut), *C* (carbon paper) and *O* (open). Various other modifications were introduced in a few of the tests, such for example as giving a subject who was drawing with his eyes closed some verbal criticisms of his results, allowing the subject to examine the resulting drawing

after it was completed, but not while it was in process of making. Other modifications may be suggested, such, for example, as allowing the subject to draw with closed eyes on soft paper and to trace with a finger of the left hand the line which has been produced in the drawing.

The subjects whose results will be utilized for this paper were members of a class in educational psychology and advanced students in the regular laboratory course. They will be designated by single letters, a given letter referring in each case to the same subject.

The writers have encountered a great deal of difficulty in preparing the results of these experiments for concise presentation. When a series of ten drawings is laid before the experimenter and the successive efforts of the subject to reproduce the pattern are compared, there is often very striking evidence of the development which has taken place during the ten drawings, but it is extremely difficult to prepare a table or curve which will adequately demonstrate these facts of development. In order to make clear the character of the results and at the same time illustrate some of the most significant characteristics of the drawing, a number of series of drawings are reproduced in Figs 94 and 95. These reproductions are one sixteenth the size of the actual drawings. Fig. 94 shows two full series with subjects *F* and *W*, both drawing in this case with eyes closed. Above the two series of drawings from these subjects, is shown the pattern which they were trying to reproduce.

Considering the series *A*, which is from subject *F*, certain facts regarding the subject's perceptual development are very evident. The first drawing is correct in general outline, but very vague in its details. The subject has here a percept comparable to that which most persons have of an object which has been observed superficially but not examined in detail. The face of a comparative stranger, for example, or the form of a plant or wall paper pattern are first recognized in gross general outline. The second drawing shows progress in that the details now begin to be correctly reproduced. The first part of the figure has evidently received not merely a vague general inspection, but has been examined in detail. The slow

rate at which the details of a percept are recognized is here strikingly illustrated in the fact that an adult who is perfectly familiar with lines of this character does not succeed in ten seconds in clearing up more than five lines. Furthermore, the fourth and fifth lines are sufficiently different from the pattern to be recognized as rough approximations rather than fully recognized details. The general form of the figure is main-

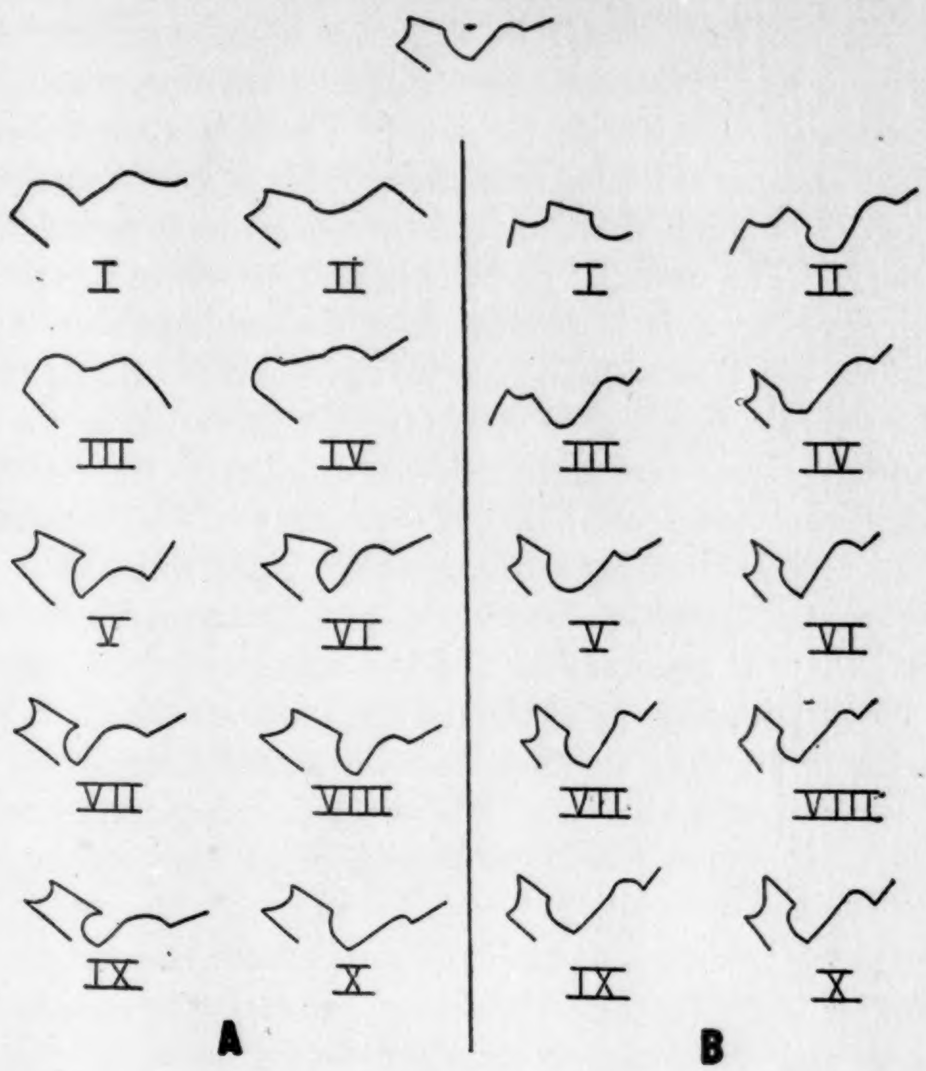


FIG. 94.

tained while the details of the first part are being worked out. In drawing 3 is illustrated a fact which comes out time and time again with almost every subject. There appears in the course of perceptual development a certain point where readjustment of the recognition of the parts is so actively under way that if the subject is interrupted before the readjustment

is complete, the reproduction shows the greatest confusion. Thus, in drawing 3 what had been gained in drawing 2 seems to be wholly lost. Moreover, the general form of the figure which was approximated in the first drawing is here much less correctly reproduced than in either of the preceding figures. Such a poor reproduction as that in drawing 3 must be recognized as very striking evidence of the complexity of the perceptual process. The explanation of the period of confusion can be made out very clearly in this case by an examination of drawing 4 and reference to the subject's introspections. The introspective record is as follows: "There is a succession of straight and curved lines, but their order is very confused in my mind. I think there should be more curves especially at the end." The essential point is in this reference to the end. From drawing 4 it is evident that the subject is trying to straighten out the confusion at the right end. The right end of the figure was vague in drawings 1 and 2. In 2 the first part of the figure was mastered. In turning to the right end the confusion arises, as shown in drawing 3. The subject has not had time in drawing 3 to master the right end. This was finally accomplished in drawing 4, but the attention is withdrawn from the general form of the figure and from the first part of the drawing in the effort to work out the last part. Drawing 3 is a very striking example of the difficulty of any single test of mental ability. Without drawings 1, 2, and 4, a very false notion would be gained of the subject's mental condition from drawing 3.

Drawing 4 shows, as has been pointed out, the mastery of the end of the drawing. It also shows that the subject has mastered a general characteristic of the figure which consists in the alternation of curved and straight lines. The introspective records show that this principle has been explicitly recognized. That the perceptual record of the first part of the figure is wholly incorrect shows what is certainly a general tendency in adult mental processes, namely, the tendency to generalize perceptual experiences under some abstract statement and neglect the perceptual details out of which the abstract statement grew. The subject of these tests must have

seen the succession of straight lines and curves, but was evidently more attracted by the abstract relational fact of succession than by the concrete forms of the parts of the figure. The concrete relations were recognized only at the end of the figure towards which perceptual attention had been definitely attracted.

Drawing 5 shows the mastery of the figure. Its relation to the earlier processes of distribution of attention, of mastery of parts, of confusion and recognition of the general principle of alternation is sufficiently obvious from what has been said. This drawing could not be understood at all if it had been preceded merely by drawing 4 or by 3 and 4. The mastery of the first part of the drawing, as shown in drawing 2, is an essential part of the preparation for drawing 5. Though the elements mastered in drawing 2 have been for a time neglected in drawing 3 and 4, they can be more easily recovered than at first. In drawing 2 there is evidence that if the subject attended to the first part of the figure, he could not at the same time include in a single process of recognition the last part of the figure. Putting the matter in quantitative terms, we may say that the scope of perceptual consciousness, as evidenced in drawing 2, is three clear lines and two vague lines. In drawing 5 the first five lines are recovered with sufficient ease so that the scope of perceptual consciousness extends over all seven lines. The greater inclusiveness of perceptual consciousness in drawing 5 gives evidence of a facilitation in some degree of the perception of the first five lines, and since this facilitation did not occur during the period occupied in drawings 3 and 4, it must have been carried over from the period of drawing 2.

The remaining drawings of this series show certain details which are typical. Thus the angle of line three deteriorates instead of improves through the later drawings of the series. This may be connected with the fact that the greatest error in all the later drawings is to be found in the angle of line four. There is very noticeable variation in the position of line four. In drawing 8 it is better than in drawing 7, but in 9 it is again worse than in drawing 8. In drawing 10 there is a very decided improvement in the position of line four. There is, on

the other hand, in drawing 10, not merely the deterioration of line three noted above, but also a very marked lapse in the length of line six. Other similar facts will be obvious from the figures.

The various lapses and slight improvements in the last five drawings show very clearly why there is so little improvement in our ordinary perception of complex figures. Attention is from moment to moment fastened upon this or that detail of the figure and there is a corresponding withdrawal of attention from some other part. The complete mastery of all the details is therefore a long process. In most ordinary experiences the interval between observations is so long that the lapses more than make up for the periods of improvement and so we have merely crude approximations to complete and correct percepts.

Another general fact shown by the series as a whole is that the size of the figures is throughout too large. Indeed, there was a very general tendency, as will be shown later, on the part of all the subjects to make mistakes in the size of the drawings. The significant fact in this immediate connection is that the subject was in no case conscious of the error in size. That is evidently a matter upon which attention must be especially directed. While attention is on the various lines and their positions, there is no attention for the characteristic of size.

Some use has been made of the introspective record. In all of the experiments the subjects were allowed to make whatever comments they would make voluntarily. They were not questioned because that would have served to concentrate the attention of the drawer upon matters in which the experimenter might be interested. The voluntary observations were very meager on the whole. The process of perceptual recognition was not to any great extent clear to the subjects. This would seem to indicate that ideas about one's own perceptual processes constitute, as does size, yet another separate item of possible attention. While attention is concentrated on the lines of the figure, one is not observing the direction of attention itself. This is merely a concrete example of the criticism often made of the purely introspective method. Reference to the criticism here is justified both by the concrete example furnished

by these experiments and by the fact that an emphatic assertion of the distinction between perception and ideation is required for an intelligent understanding of the results themselves, as was made clear in the discussion of drawing 3.

It may be well to pause in the description of these results and meet a possible objection which may be raised to the explanations. It may be said by some that the variations in the figures are due to memory conditions rather than to purely perceptual processes. The experiments, it will then be said, are tests of memory rather than of perception. In a certain measure it must be recognized that memory is involved in all these tests. But there is no complex percept which can be built up without memory. It is clear from our examination of drawing 5 in Fig. 94, *A*, that the effects of earlier stages of the perceptual process are clearly present in the fifth stage. The complete recognition of figures is thus a gradual development which involves a certain amount of retention. The retention will, however, indicate by its content and fullness the character of the perceptual process. Thus it is obvious in drawing 2 that the last part of the figure was not as clearly apprehended as the first part. It makes no difference whether the statement is made with reference to the retention or the original recognition. This is perfectly clear when it is noted that in drawing 4 the emphasis is obviously on the last part of the figure rather than the first. Drawing 5 shows the necessity of considering in any discussion of perception the retention of earlier influences and at the same time shows the purely perceptual problem of the tests, for while the interval between the inspection of the pattern and the drawing is the same as in earlier cases, the product is totally different in character and shows clearly the dependence of the product upon the clearness and fullness of mastery of the figure. The tests should not be criticized because they involve memory, it should rather be recognized that all perception involves memory, the memory phase being in general overlooked by any purely analytical method of examining experience.

Turning to series *B* in Fig. 94, we find an entirely different type of development from that shown in series *A*. Instead

of beginning with a recognition of the general form of the figure and neglecting details as did the subject in series *A,* this subject began by making an effort to master the details as they appear at the beginning of the figure. The subject's introspection is: "Too many lines. Couldn't get the direction of the lines after the first three." Drawing 2 shows that the attention was devoted to filling out the figure, even though the image of the first part was left with all of its original defects. The introspection is as follows: "Saw distinctly a straight line, then a curve, alternating four of each." This is a vague ideational formulation of the principle of the figure. As a matter of perception the number of straight lines is correctly given, though the curves are not correctly reported.

The further development of this series need not be discussed in detail except to call attention to the lapse in line six of drawing 5. In drawing 4 there is clear evidence that the subject was interested chiefly in the early part of the figure. The introspections for drawings 4 and 5 show this concentration of attention on the first part of the figure. After drawing 4 the subject records: "Positive about number of curved and straight lines, but direction of second curve vague. After a little effort more distinct." After drawing 5 the subject records: "Direction of curved line after second straight line vague." Since the attention was on the first part of the figure, the curve toward the end was neglected with the resulting error shown in drawing 5.

It will be noticed that in point of size figures 9 and 10 are among the worst in the series. This shows again that while one phase of experience is improving other phases may deteriorate.

The records reproduced in Fig. 94 show that the most radical changes in the records occur in the first part of each series. This is true in general of all series for all subjects. The number of lines in the pattern might have been increased and then the serious errors would have appeared through a larger part of the series. The conditions being as they are, we can present most of the striking material in a number of series in a single figure, by reproducing only the first five drawings in each of

four series from different subjects. The series *A* from subject *O* was made with carbon paper. Series *B* from subject *D* was made with eyes open. Series *E* from subject *E* was made with eyes shut. Series *D* is from subject *W* and was made with carbon paper.

The most striking characteristic of series *A* is the persistent

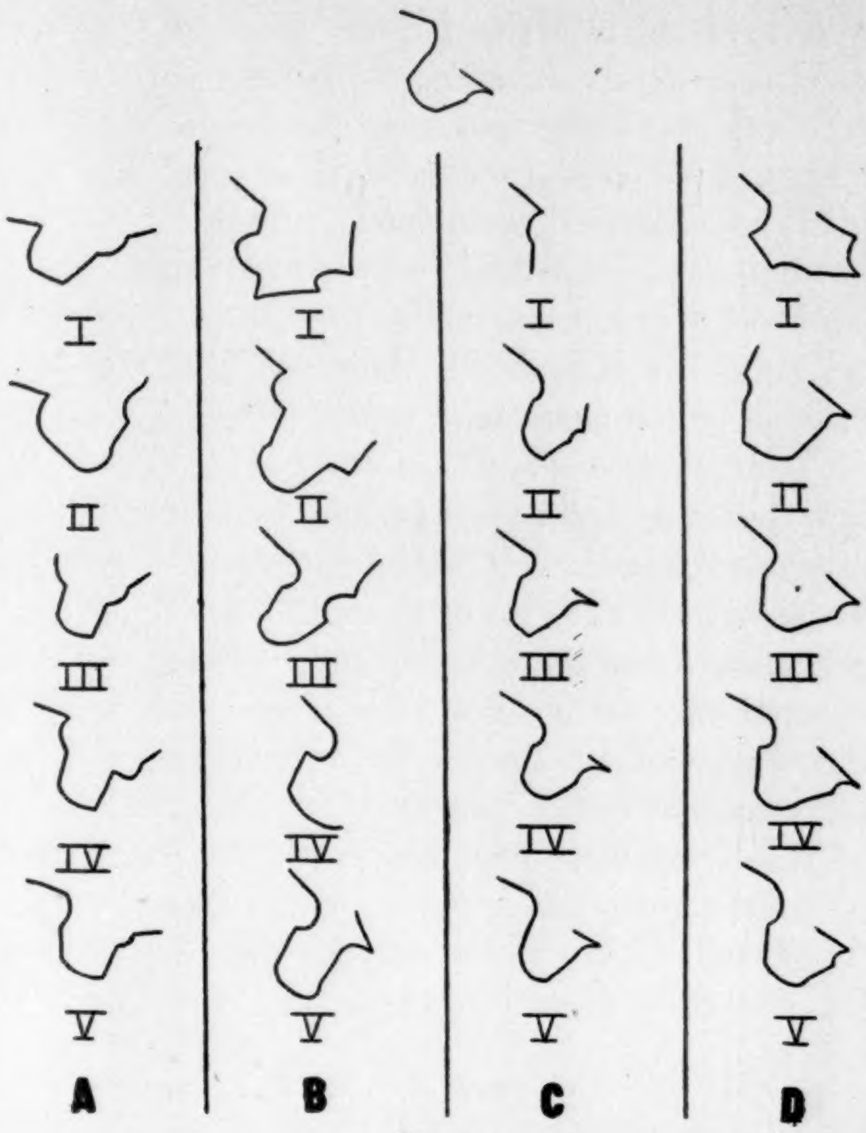


FIG. 95.

error in line seven. It may be remarked that this continued throughout the whole series of ten drawings. As contrasted with the series with closed eyes from this same subject, the carbon paper series seem to show greater distractions.

The striking fact in series *B* is the loss in drawing 4 of the last part of the figure. This is a series with open eyes and yet its results are very much like those shown in *A*, Fig. 94.

Series *C* shows a very typical series for this subject. In no case does this subject attempt to reproduce the whole figure, but always begins with the beginning and gradually masters the figure. The size is better here also than in most of the series.

Series *D* from the same subject as the series *B*, Fig. 94, is reported for the purpose of making it clear that this subject had no such systematic habit of attacking the figures as did subject *E* reported in series *C*. In drawing 2 of series *D*, subject *W* is evidently attending to the last part of the figure and perfecting that before attacking the details of the first part of the figure. Otherwise the series is so much like those discussed that no additional comments are needed.

The analysis of individual series is undoubtedly from many points of view the most productive method of using the results of these tests. It is desirable, however, that the individual results should be compared with results from other subjects and that the same subject should use different figures. For this purpose a system of figures was prepared which should be comparable with one another. The two patterns in Figs. 94 and 95 were members of this system of figures. Each figure was made up of seven lines, four straight and three curved. In constructing the series the relative positions of the lines were varied, otherwise they were repeated without modification in the successive figures, that is, the lengths of the straight lines and the radii of the curves were kept constant throughout the series. With nine such figures six subjects were carried through series of ten drawings. Two of the subjects drew each figure with eyes shut, two drew on carbon paper, and two drew with eyes open.

TABLE I.

Subjects.	Figures.									Total O.	Total S.	Total C.	Total for Subject.
	1	2	3	4	5	6	7	8	9				
E	O-4	S-3	C-2	O-5	S-3	C-4	O-8	S-4	C-5	17	10	11	38
J	O-2	S-3	C-3	O-2	S-4	C-1	O-2	S-4	C-2	6	11	6	23
B	C-1	O-4	S-1	C-5	O-2	S-3	C-3	O-1	S-1	7	5	9	21
H	C-7	O-1	S-5	C-4	O-2	S-3	C-6	O-1	S-3	4	11	17	32
O	S-1	C-10	O-1	S-4	C-1	O-3	S-1	C-2	O-2	6	6	13	25
W	S-4	C-3	O-2	S-2	C-1	O-1	S-1	C-1	O-3	6	7	5	18
Total.	19	24	14	22	13	15	21	13	16	46	50	61	

The most general question which can be asked is, how long does it take for a given subject to master a figure so that he can reproduce it without gross error? In defining what was meant by a gross error, no attention was paid to errors in the length of lines. If a line was omitted, if a curve was in the place of a straight line or the converse, if a convex curve was represented as concave, if a line was $75°$ or more out of place, the error was regarded as gross. Table I. summarizes the results for six subjects drawing nine figures.

It appears from this table (last column at right) that there are marked individual differences in the different subjects. The difference between *E* and *W* is twenty figures in the total series. Such a difference can not be attributed to any accidental differences in the conditions or in the distribution of figures, it must be interpreted as exhibiting a distinct individual difference. Again comparing *B* with *H*, it is seen that although these subjects worked under the same conditions with the several figures, their results are different and this difference appears in detail also, there being only two cases out of nine in which *B* required more trials to master the figure than *H*. In the second place, the table throws light upon the question of which conditions were most valuable for drawing. When the test was undertaken it was assumed that the drawing would be most accurate when the subjects were allowed to see the results of their work, that is, when they were allowed to keep their eyes open. This expectation was confirmed in general, as shown in the totals under the columns showing the number of trials necessary for *O, S,* and *C* respectively. But there is no great difference between the number of trials necessary to master the figures with the eyes open and with the eyes closed. The carbon drawing is very much more decidedly disadvantageous.

If, now, we turn from the general result to the consideration of individual subjects, we find many cases in which the expectation that the drawing would be most accurate when the figures were seen with the eyes open is not confirmed. Thus subject *E* gives the best results with the eyes shut and very poor results when the eyes are open. The introspections of this

subject throw more light on this result. The observation is repeatedly made that there is confusion because the lines which the subject has drawn disturb the recollection of the pattern. "There is much less confusion when I can consider the figure with my eyes closed and not be disturbed by the results of my own drawing." Again, in such a case as that of subject *B*, *O*, or *W*, it is seen that there is practically no advantage in the opening of the eyes, at least so far as the general mastery of the figure is concerned. There is one respect in which the opening of the eyes is a very distinct advantage. The results presented in the table with regard to the advantages of the different conditions should be somewhat qualified by the fact that no attention is given in this table to the length of the lines. It was true in general that the size of the figure was better when the eyes were open, although the differences here did not seem so essential as the differences which were involved in the mastery of the figure—the matter dealt with in Table I. The result that the drawing was as good in its essential outlines with the eyes closed as with the eyes open makes it clear that the amount of sensory experience received by the subject is not the important matter. It is very much more important that the sensations should be properly arranged with reference to each other in the subject's experience. This comes out very clearly when we consider the fact that the carbon drawing was decidedly disadvantageous. There was in this case an excess of sensory experience because the lines on the defaced carbon paper were somewhat distracting. Furthermore, what sensations there were, in the way of visual experience from the moving hand and muscle sensations from the hand itself, were not given in the usual combination, and consequently confused rather than assisted the subject. The test is, accordingly, very clear as a test showing lack of direct dependence of perception on sensation. Possibly a larger number of experiments would throw more light on this question, for it is obvious from the total results referred to a moment ago that the conditions are in general more advantageous when the eyes are open and least advantageous when there is much confused sensory experience, as in the case of the carbon drawing.

In the third place, the table should be discussed with reference to the relative difficulty of the different figures used as patterns. The totals in the bottom column of Table I. show the number of trials for all of the different subjects necessary to the mastery of any given figure. The experiment was so arranged that two of the subjects in each case used the pattern with the eyes closed, two with the eyes open, and two with the carbon paper. If a sufficient number of cases were present there ought to be a possibility, by the comparison of these different subjects under the different conditions, of determining the relative ease or difficulty of the figures. Nothing very definite comes from the comparison, however, except the general fact that there was not sufficient difference in the different figures to explain the individual differences in the last vertical column, which have been utilized before as the basis of the discussion of individual differences.

There is also no decisive answer, on account of the small number of trials, to the question whether the subjects improved during the nine successive series. The introspections show that some of the subjects learned with regard to the successive figures that they were made up in the same way, and one discovered that the elements were 'probably the same' in all the different figures, but beyond this point there is no clear evidence of overlapping of training. In view of the interest which has been taken in this problem of the transfer of training, it may not be out of place to remark that the discussion is introduced here rather for the sake of calling attention to the danger that there is in appealing to a small number of tests such as here given, for negative conclusions. The whole experiment shows very clearly how complicated the problem is and how many different factors must be considered in even the simple perceptual recognition of these figures. To draw the conclusion, on the basis of the five hundred and forty tests here reported, that there is or is not a transfer of training in successive cases, would be to neglect the whole problem of psychological analysis of the process of learning and to give an empty, formal treatment to the results here tabulated.

TABLE II.

Subjects.	Lines.							Totals
	1	2	3	4	5	6	7	
E	5	13	17	47	63	58	54	257
J	9	19	17	30	56	59	32	222
B	21	30	47	54	43	23	17	235
H	17	36	41	62	58	24	28	266
O	13	24	19	55	49	47	36	243
W	24	21	31	37	41	24	21	199
Totals.	89	143	172	285	310	235	188	

Turning now from the general results reported in Table I. to another matter which can be treated in general, we may inquire what part of the figure is most accurately drawn by the different subjects. In securing a general statement of the errors in the different parts of the figure, a somewhat arbitrary procedure was adopted. Any line was regarded as constituting an error if it was omitted, if it differed from the pattern by 2 cm. or more in length, if its character was changed from a curve to a straight line or the converse, if it was more than 30° from the position given in the pattern. In making the determinations of length and position the curves were dealt with in terms of their chords and not in terms of the arc itself. Table II. shows the number of errors for each of the lines in the ninety trials with each of the subjects. Thus, the horizontal column given opposite the letter *E* indicates that there were five errors in the first line of the ninety drawings for subject *E,* thirteen errors in the second line, and so on. The total number of possible errors was 630 for any given subject. The totals given in the last vertical column show the total error in all of the drawings. The horizontal column at the bottom of the table gives in very striking form the general result. The great majority of subjects drew with relatively great accuracy the first three lines of the figure. There then followed three lines which were always centers of the greatest error; the final line of the figure was again drawn with relatively great accuracy.

Turning from this general result to the records of the various subjects, we find some striking details with regard to the mode of attacking the figure by the different subjects. One of

the most striking cases is that of subject *E*. This subject always began at the beginning of the figure and drew in the first drawing usually three, or at most four lines. The second and third drawings were usually devoted to the mastery of the figure. The results as formulated in Table II. show that there is very little error in this subject's drawing of the first three lines, and very large error for the last four lines, amounting in one case to errors in more than two thirds of the figures. Somewhat similar results appear in the case of subject *J*. Here again it is the first part of the figure which is most accurately drawn. With subject *B*, on the other hand, there is equally clear evidence that the last part of the figure is emphasized. The general procedure on the part of this subject was to draw the figure first with reference to its general form, getting two or three of the lines properly placed and all approximately the right length. The drawing was then refined from the right end toward the left, with the result exhibited in this table that the errors are least in the case of the last line toward the right. Of the other subjects *W* is perhaps the most interesting case. This subject had no definite order of procedure, but corrected in some cases the right end of the figure first and in some cases the left end. The result is that the extremities of the figure and the middle are on the average much nearer to each other than in the case of any of the other subjects. It will be seen from a comparison of the total number of errors here recorded for *W* with the number of trials necessary to master the figure as exhibited for this same subject in Table I., that this subject was superior to the others in ability to draw the figures. Other correlations between the subjects can be made by comparing Tables I. and II. Thus, *H* is high in both cases, although in Table I., *H* is not as high as subject *E*.

Several of the irregularities in Table II. can be accounted for by the fact that the curves were somewhat more difficult to draw correctly than the straight lines. Thus, it will be seen that in the record of subject *O*, the second line, which is a curve, gives notably more errors than the third line, which is a straight line, but which from its position is in general more subject to error. The same fact appears in comparing the second

and third lines for subject *J*. The fourth line, which is also a curve, shows great errors for *O, H,* and *B*. The sixth line, which is a curve, shows large errors for *J*. This difference of error in the curved line should not be attributed to the fact that there is in the series of errors upon which the table was based one type of error which belongs exclusively to the curved lines; namely, confusion between concave and convex curves. This particular error did not occur a sufficient number of times to account for the excesses pointed out in the table.

The figures were in general drawn too large. In no cases were the figures drawn too small throughout a given series except where the eyes were closed. This is shown very strik-

TABLE III.

SUBJECT J.

Figures.								
O-1	S-2	C-3	O-4	S-5	C-6	O-7	S-8	C-9
8	-5	2	1	1	6	9	0	7
6	-1	4	3	-4	1	7	2	7
4	-2	8	3	-4	5	9	-6	7
11	-2	0	10	-2	5	12	-5	9
9	-4	-1	6	0	2	12	-6	7

ingly in the case of subject *J.*, in Table III. This table shows for each of the figures the total error in length for each of the first five trials. These errors were measured by rotating over the drawing a small wheel of known diameter which was connected with a reading dial. The total distance traversed by this wheel was then compared with the distance which it traveled in passing over the pattern, and the error in full centimeters is recorded in the table. There is some error in this method of measurement because it is not possible to follow with perfect accuracy the outlines of the figure. The results are presented therefore only in centimeters. Two characteristics, however, are perfectly clear. In the first place, the drawings with the eyes shut were for the most part too small, while all of the other drawings were too large. In the second place, there is greater irregularity in this matter of size than in any other phase of the figure. There is obviously no improvement during the latter part of the test, as shown by the

excessive errors in figures 7, 8, and 9, unless indeed the large errors in length exhibited in these figures are themselves to be regarded as the expressions of a progressive tendency or product of practice. The error would in this case constitute a kind of negative development. It should be remarked that this table is characteristic of the results for two other subjects. Some of the subjects, however, did not show this tendency to make the figures drawn with closed eyes too small; some of them showed a general tendency to make all of the figures too large.

A general observation which can be made with regard to the drawings of all the subjects is that attention is seldom concentrated at the same time on improvements in the relative angles between the lines and the lengths of the lines. Many of the subjects gave attention in a particular case either to the size or angles, but they did not at the same time attend to both of these phases of the figure. As a means of analysis the successive drawings serve clearly to justify the distinction between the sensory and perceptual processes which are involved in recognizing position and size.

Another distinction which comes out clearly in the results is a distinction between perceptual and ideational processes. Very frequently, as noted above, the subject was quite unable in his introspections to give any definite account of his attention during the introspection of the pattern or the drawing of the figure. In some cases, to be sure, he carried over ideas from one drawing to the next and governed his attention in terms of these ideas. Thus, we find the observation repeatedly made that 'the last drawing was too small,' and in the subsequent drawings we are likely to find some improvement along this line. On the other hand, there are equally numerous cases in which the introspective observation is recorded after the adjustment has been made. The observer evidently noted during the examination of the pattern that his preceding drawing had been too large or too small. The idea came to him in such a case as this while introspecting the pattern and not while he was drawing. Sometimes the idea operated so emphatically that the reaction in the opposite direction could

be noted in the successive drawings. Some effort was made to deal with this relation between the idea which the subject had with regard to his drawing and the efficiency with which he reproduced the figure.

One of the subjects who was drawing a figure too small was allowed to proceed with the experiment beyond the regular ten drawings of the series. On a number of successive days this subject drew from the same figure. Gradually improve-

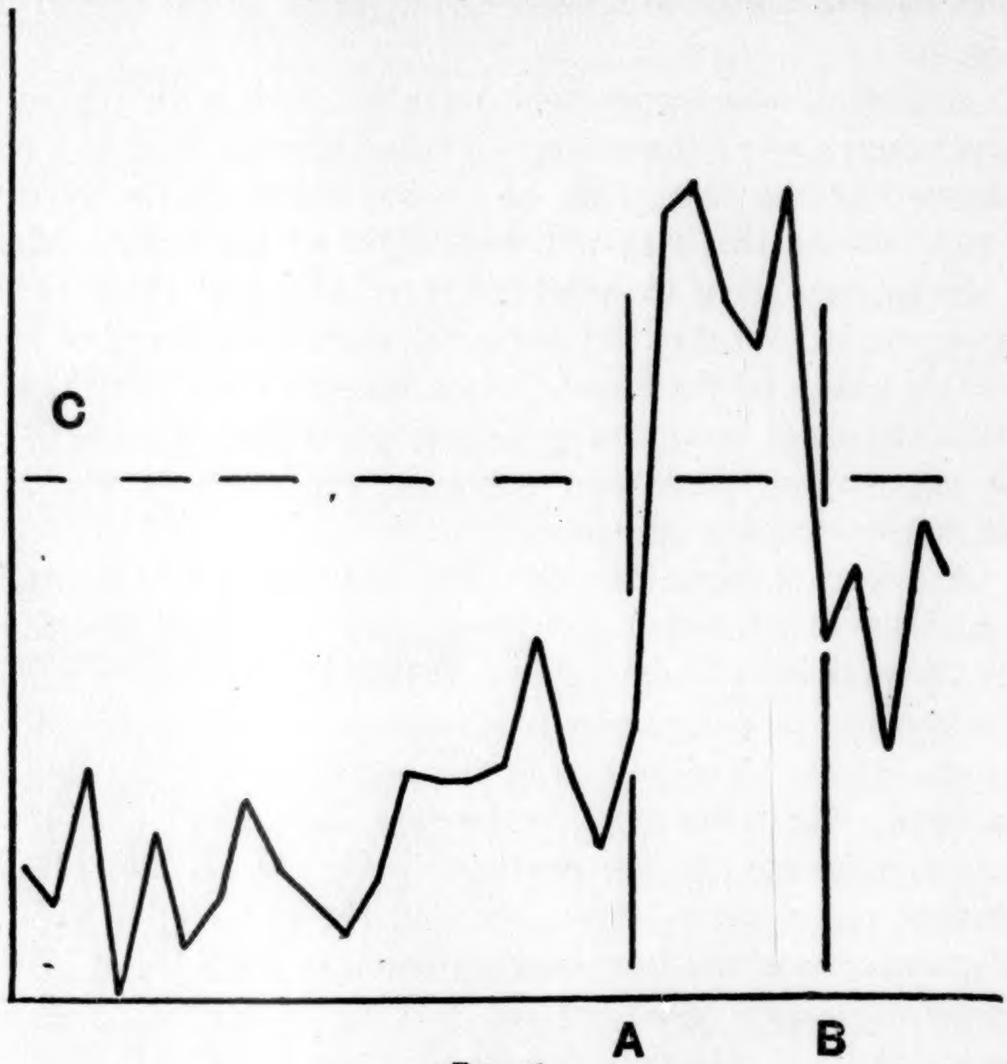


Fig. 96.

ment appeared in his drawings, although these improvements were very irregular in character. At the end of ten series, the subject was allowed to change the conditions of the experiment in such a way that he drew for two days with the results exposed to visual inspection during the drawing. After drawing for two days in this manner he returned to the original

method of drawing with his eyes closed. The results of this series of experiments were presented in Fig. 96 in the form of a curve. The broken line *C* represents the normal length of one of the lines in the figure, this being 6 cm. The line was drawn during the first five trials with a length of approximately half that of the standard. The first point in the curve represents the average of these five drawings. During the next five drawings the length was somewhat further from the standard length than at the beginning. During the third series of five drawings the length of the line was nearer the standard. The curve in Fig. 96 shows that there were a succession of approximations to the standard line. At the point *A* the subject was allowed to give up, as indicated above, the drawing with the eyes closed, and twenty-five tests were introduced with the eyes open. The figure shows a marked error in the positive direction. The line is drawn much too long in these five series. After these twenty-five tests were concluded and a return was made to the series with closed eyes, it will be noted that the effect of the series with the open eyes was carried over only in small part to the new series with closed eyes. There is some improvement over the last drawings with the eyes closed, but on the whole the effect of the interpolated series with the eyes open is not large. It should be stated that not all of the lines in this series of drawings conformed to the curve here exhibited. The one selected line gave a very definite result, the others were more complex.

In concluding the discussion of this series of experiments attention may once more be called to the practical utility of such a series as a means of demonstrating to students the characteristic processes which appear during perceptual development. There is an abundance of illustrative material in such a series of experiments as this which can not be reported in detail in a general paper. Enough has perhaps been reported to indicate the character of the material which can easily be obtained and some of the lines of interpretation which can be suggested to students as the basis for their own critical study of perceptual development as contrasted with ideational development or development of motor habits.

PHOTOGRAPHIC RECORDS OF CONVERGENCE AND DIVERGENCE.

By CHARLES H. JUDD.

This paper reports a series of photographs in which movements of visual convergence and divergence between two fixed points are studied for several positions of the points, namely, in the median plane between the eyes, in certain lateral positions, and especially in the position in which the two points lie directly in the axis of vision of one eye. Five subjects were examined, among them one who was blind in one eye, and consequently exhibited none of the normal forms of binocular convergence and divergence. It is shown by these photographs that there are different tendencies of behavior exhibited by the single eyes of different individuals. There are also differences in the binocular adjustments of different individuals which are probably dependent upon muscular differences in their eyes. All subjects agreed in exhibiting a tendency which is opposed to that of convergent and divergent movements in that they tend to move the two eyes in the same lateral direction. Furthermore, all subjects agree in showing a long and difficult form of adjustment in binocular convergence and divergence. Monocular adjustments are much simpler in type. The report includes certain accounts of voluntary convergence and divergence and concludes with a theoretical discussion in which the theory of coordination of sensory and motor factors is substituted for any analytical description of visual fusion.

The method employed in the investigation to be reported in this paper is in general the same as that reported in the earlier number of this volume of Yale Psychological Studies.[1] By means of a kinetoscope camera the eyes were photographed during movement, a small piece of Chinese white being placed upon the cornea so as to mark clearly in the photographs the exact position of the eye. The double camera there reported, with films which are alternately exposed, was employed throughout, though the figures presented in this article are made up from only one of the films. It is not necessary in reporting the distance and direction of the movements to utilize the results from both films, though in determining certain time relations reference will be made to the double record.

An important modification was introduced in the apparatus

[1] **Monograph Supplement No. 29 of the Psychological Review. Yale Psychological Studies, N. S., Vol. I., No. I., pp. 1–16.**

in that the camera was driven by a mechanical device. The irregularity which was apparent in the photographic series with even the most carefully trained hand movement was pointed out in the earlier paper. This irregularity has been entirely removed by the mechanical device sketched in Fig. 97. This consists of a large balance wheel *F* which is driven by an electric motor. The heavy balance wheel is necessary in order to maintain uniform motion when the camera is thrown into gearing with the driving apparatus. The balance wheel carries a hollow cone into which a solid cone (*W*) may be firmly set from above. The solid cone is in turn connected with the shaft (*S*) which drives the camera. The camera does not appear in the figure, it stands above the parts here shown. By means of the handle (*H*), which holds the solid cone in a ball-

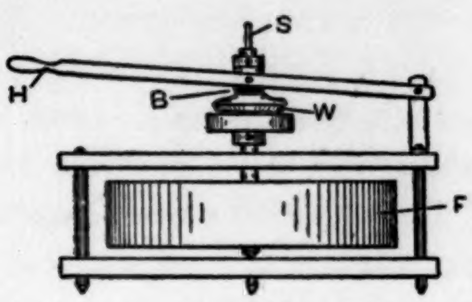


FIG. 97.

bearing collar, the solid cone may be lifted out of the hollow cone, when the shaft (*S*) will be uncoupled from the driving wheel. On the other hand, when the solid cone is set firmly into the hollow cone the shaft (*S*) will immediately be set in operation at the full speed of the driving wheel. The upward and downward movement of the shaft is taken up in a slot device at the upper end of the shaft. This form of driving apparatus makes it possible to begin a series of photographs without any delay such as would be experienced if the driving shaft were set into gradual motion. This is evidently advantageous, for it not only economizes the first and last part of the film while securing photographs at a regular rate of exposure, but it makes it possible to begin at the point of the observer's movements which will be most advantageous, with a certainty that the earliest movements will be fully recorded on the film.

In the earlier reports of the photographic methods atten-

tion was called to the fact that head movements are often present and constitute a matter for consideration in any photographic method of studying eye movements. Two steps were taken in the following investigation: one to throw further light upon this problem of head movement, and the other to eliminate as fully as possible the effects of head movement. In the first place, in order that the exact amount of head movement might be measured, a fixed rod with points of reference quite independent of the head or camera was introduced into the field and photographed with the eye. By reference to this fixed rod it was always possible to determine when a head movement occurred. It was found that head movements occurred most noticeably just before long movements of the eyes. Due to the firm head rest used in our experiments the range of these head movements was never great. No movement was recorded of more than 0.5 mm. If the eyes are looking at an external object which is fixed in its position, there can be very little doubt that there would be required even with a slight movement of half a millimeter, a compensatory eye movement in order to maintain fixation upon the object. These compensatory eye movements would lead to some confusion in the reading of the record. In order to eliminate any possible error from this source, it was possible, and indeed very easy in the investigation here reported, to so arrange that the object should move with the head. The result was that whenever the head moved in any direction the object was carried with it and there was no demand for compensatory eye movement. The objects at which the observers looked in this investigation consisted of two bright points mounted on a bamboo rod. The bamboo rod was held firmly between the teeth and supported at the extreme end on a bar across which it could very easily slide. This use of the teeth to hold the object of fixation involved the abandonment of the ordinary tooth-rest connected with the general head support. The head was supported from the side and back by means of adjustable rods fastened to the seat. Even with the removal of the tooth-rest the head movements, as noted above, were not very conspicuous, while the additional precaution taken in fixing the object to the head was sufficient

to insure absolute freedom from error through head movement.

It may be well in this connection to call attention again to the advantage of one feature of the method which has been employed in all of the photographs taken in the Yale laboratory. The points of reference in all of these experiments have been attached to the head, so that when any head movement takes place, the eyes and the points of reference move together. It is only when the eyes move with reference to the head, therefore, that a record is produced in the photographs. Any method in which the measurements are made with reference to a fixed plate or other point of reference detached from the head will always lead to a confusion of head movements with movements of the eyes within the head. If movements of the eyes are measured with reference to a fixed plate and at the same time the object fixated is detached from the head, then any head movement for which there is at the same time a compensatory eye movement will result in a double error. First, there will be an error because of the movement of the head carrying the eyes into a new position with reference to the plate, and second, there will be an error which arises from a compensatory eye movement executed by the eyes in the maintenance of fixation upon the object of regard. The elimination of any possibility of confusing head movements with movements of the eyes in the head was secured from the very first by the method of attaching the points of reference to the head itself.

In his paper in the PSYCHOLOGICAL BULLETIN of March, 1906, Professor Dodge (page 88) criticizes the use of points of fixation attached to the head on the ground that any head movement must first be measured by certain changes in the relation between the points of fixation, and must then be added as a correction to the records of the eye movements. The real significance of attaching the points of reference to the head seems to have escaped Professor Dodge entirely. The purpose is to prevent the head movement as measured with reference to a fixed plate from being confused with movements of the eyes in the head. These latter movements are the only movements of importance, unless we aim to distinguish between

eye movements which are primary and eye movements which are compensatory. In order to meet Professor Dodge's criticism empirically a number of cases were examined in which there is a distinct record of head movement. The relation of the eyes to the points of fixation is shown in four distinct cases of this kind to be constant in spite of the movement of the head. This furnishes empirical justification for the method in answer to the purely theoretical calculations undertaken in the criticisms referred to.

Before reporting the results of the present series of photographs, it may be well to describe somewhat fully the meaning of the complicated figures which it is necessary to employ. The figures are complex because of the necessity of represent-

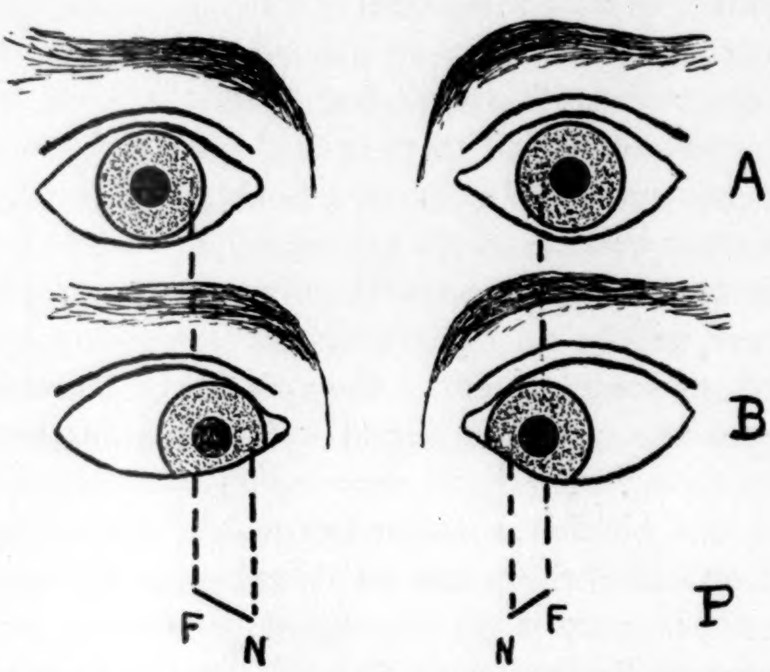


FIG. 98. In the two eyes *A*, fixation is at a point infinitely distant. In *B* the eyes are shown converging on a near point. The convergence here represented is extreme. Th vertical dotted lines show projections of the 'white spot' to the lower part of the figure *P*. The positions *F, F* show the projection of the non-convergent eyes. The downward slope of the lines *FN, FN* indicate the downward movement of each eye in convergence. The positions *N, N* are the projections of the convergent eyes.

ing in a single figure lateral movements and, where they exist, movements upward and downward in the vertical plane. The appearance of the eyes as they are shown in the photographs is schematically illustrated in Fig. 98. The irises are shown in

similar setting of eyelids in two successive positions. These two positions can be projected as shown by the vertical lines and can be very fully represented by the lines *NF* and *FN*. The line on the left indicates that the left eye has moved inward and downward, while the line on the right indicates that the right eye has moved downward and inward. The double movement of the two eyes constitutes a movement of convergence. If the two straight lines are read in the directions *NF* and *NF* they indicate a movement of divergence of the two eyes. Their downward slope indicates that in moving toward the nearer point the eyes not only converge laterally, but also moved downward. If a succession of such movements is to be indicated the successive backward and forward movements can be indicated by a succession of distinct lines placed vertically one under the other.

In the figures reported in this paper the successive lines indicating backward and forward movements are connected by means of dotted lines which are intended merely to show the relation between the end of a given movement and the beginning of the next successive movement. Thus, as will be seen by referring to Fig. 99, photographs 1–10 in the left-hand side of the figure were taken while the left eye remained fixed at a given point. Photograph 11 showed a slight movement of the eye inward toward the nose in a horizontal line. Photograph 12 indicated a further movement in the same direction. The eye remained in this position while exposure 13 was being made. In photograph 14 the eye had reached a still further point of inward movement. At 15 it reached its extreme position of convergence and remained at this point up to and including photograph 21. After photograph 21, the eye made a slow divergent movement back to a position very near to that occupied in photograph 1. This backward or divergent movement is indicated in the full-drawn line 21–22–23–24. The beginning of this line 21–24 is related to the end of the line 1–15 by means of the vertical dotted line which shows the relative positions of the photographs taken during divergence as compared with those taken during convergence. The inward and outward movements represented on the left-hand side of

the figure are for the left eye. They are directly related to the inward and outward movements represented on the right-hand side of the figure for the right eye. It will here be seen that the right eye remains fixed in a given position during the first nine photographs. The right eye began its convergent movement somewhat earlier than the left eye, with the result that it reached the position marked 10 while the left eye was still fixated at its original point. The right eye continued in this position during exposure No. 11. From 11–12 the right eye made the long movement of convergence by which it reached its final position of near fixation. This is indicated in the figure at the right by the completion of the line at 12. The right eye now remains fixed at the point 12 during the whole period of movement in the left eye from 12–15. At 21 the two eyes begin a movement of divergence which proceeds at about the same rate in the two eyes, as indicated by the line 21–22–23–24 on the right. It should be noted again that the photographs in this paper report the results from one film only. If the second film taken with the one reported in Fig. 99 is drawn upon for results, it is found that the movement for the left eye from 11–12 is a slow, continuous movement. This is indicated by the fact that the photograph on the second film which was taken between 11 and 12 indicates that the eye occupied between 11 and 12 a position midway between the points indicated in the figure here presented. The movement from 14–15, on the other hand, is a much more rapid movement. After the exposure 14, there appears on the other film a photograph which shows that the eye moves rapidly to the position 15 and has reached that position before the photograph 15 represented in the figure is taken. In this way it is possible to interpolate between the photographs reported in the figures other photographs which shall increase the precision of time estimations. Thus the average time of the exposures represented in Fig. 99 is 94 σ, while the time calculations can be made by interpolating the second film for periods of 47 σ. This 47 σ can be relied upon in these photographs to be within a probable average error of 2 σ; the time estimations are therefore fairly accurate and the inferences which will be based in

this report on time relations will be restricted to those which are justified by periods of the length here under discussion.

The special problem taken up for investigation in the photographs to be reported in this series is the problem of simple movements of convergence and divergence between two fixed points. These points were placed directly in the median plane between the two eyes or brought into position directly in front of one or the other eye. In some cases the nearer point was somewhat lower than the more remote point, in others the converse relation obtained. The distance of the points was so arranged that the movements of convergence would be clearly marked. No effort was made to vary this distance through any long series of variations. Such additional measurements of different distances as well as other conditions of convergence are very desirable and will ultimately be undertaken. The range of the present investigations was determined by the necessity of solving first of all the definite though relatively simple problem of convergence and divergence within fixed limits. Five subjects were investigated in this series. Mr. Kerrigan and Mr. Cockayne gave a series each, showing the character of their convergent and divergent eye movements when the objects lie in the median plane between the two eyes. Dr. Cameron and the writer were photographed for a variety of different positions and under a number of different conditions. The fifth subject, Mr. G., was an extremely interesting subject for the particular investigation here in hand. Mr. G. is blind in the right eye and has been blind in that eye for a period of about fifteen years. He lost the sight of this eye in an accident when twelve years old. The blindness is due to opaqueness of the lens which was injured by accident. The subject can see vague images and recognizes at times when looking at a bright object that he has double images, especially when his eyes are fatigued. For the most part, however, he neglects entirely the images from the blind eye, these being in any case extremely vague and indefinite. Mr. G. was the subject in several series of photographs which will be reported in full in this paper.

In the course of this investigation it was possible inciden-

tally to secure data on two minor problems which may be disposed of immediately since they are not of importance in the general report. First, in order to secure data on the amount of rotation which occurs during convergence and divergence, one of the subjects was photographed with two white spots on each cornea. When the eye moved in any direction these two spots made it easily possible to determine whether the movement of the whole eye was in the same direction or whether a movement of rotation took place in connection with the general movement of the eye. It was found in a number of cases that when the eye made a long movement of convergence or divergence, rotation factors were involved. In several cases when the eye moved in the convergent direction there was a tendency toward rotation in a clockwise direction through an angle amounting in some cases to 2°. The amount of rotation it will be seen from this statement was slight. Some effort to estimate the probable limits of error in the photographs indicated that the error in reading might amount to 30 min. of arc. Furthermore, it was found that in all cases except one the rotation observed during the movement of convergence was corrected in the later phases of movement as the eye came to its position of final fixation. In the general movement of convergence with which we are concerned in the figures and in this report, rotation plays no appreciable part. The rotation seems to be a phase of movement proper during the adjustment rather than at its termination. Movements of rotation in divergence were also observed in several cases. These movements were both clockwise and anti-clockwise, there being three cases of the latter and two of the former observed in the course of these experiments. The range of these rotations is slightly greater than the range of rotation observed during movements of convergence. It amounted in one case to 3.5°, but was corrected during the last movement by which the eye came to its final position of fixation. This movement of rotation, which was the largest observed in the series, made a difference of less than one half a millimeter in the record as reported in the figures. It was, therefore, well within the probable error of the general observation reported and can be eliminated entirely

from any consideration. The matter of rotation to be productively worked out will require much greater ranges of movement than those with which these results deal.

A second incidental matter to which reference may be made was observed in connection with one series of especially clear photographs in which the eyelid was shown with sufficient clearness in the photographs to be definitely measured in its position. The series of photographs in question involved a downward movement of the eyes during convergence, and it was observed that the downward movement of the eyes was in general accompanied by a downward movement of the eyelids. Indeed, it was clear in two cases that the downward movement of the lids preceded the downward movement of the eye itself. Photograph 42 in one case indicated a downward movement of the lid without any downward movement whatsoever of the eye itself; photograph 43 indicated the downward movement of the eye. The upward movements seemed to be somewhat more irregular in character. In one case a movement of the lid which was evidently a slight movement of winking occurred without any reference whatsoever to the eye movement and at a period when the eye was steadily fixating a single point.

Turning from these incidental matters to the main subject of the report, we may consider first four typical series from different subjects showing the character of the coördination movements when the points of fixation are in or near the median plane and at about the horizontal level of the eyes. Records of this sort are shown in Figs. 99–102. All of these figures show that in converging and diverging upon a point of fixation the two eyes do not in most cases follow paths of the same form nor do they proceed with the same degree of rapidity. The lack of similarity in the motion of the two eyes is here very much more conspicuous than in any of the earlier series of photographs reported in No. 1 of the Yale Studies, where the eyes executed in all series merely lateral movements and did not change their degree of convergence or divergence. It was there noted in a number of instances that the two eyes do not follow exactly the same path or show the same rate of movement, but the incoördination was incidental in that case, in

these results it is a very obvious and primary fact. For example, it will be seen on examining Fig. 99 that the left eye requires for the complete movement of convergence the first time it moves from the remote point to the nearer point a period of about 375 σ, whereas the right eye of the same subject requires

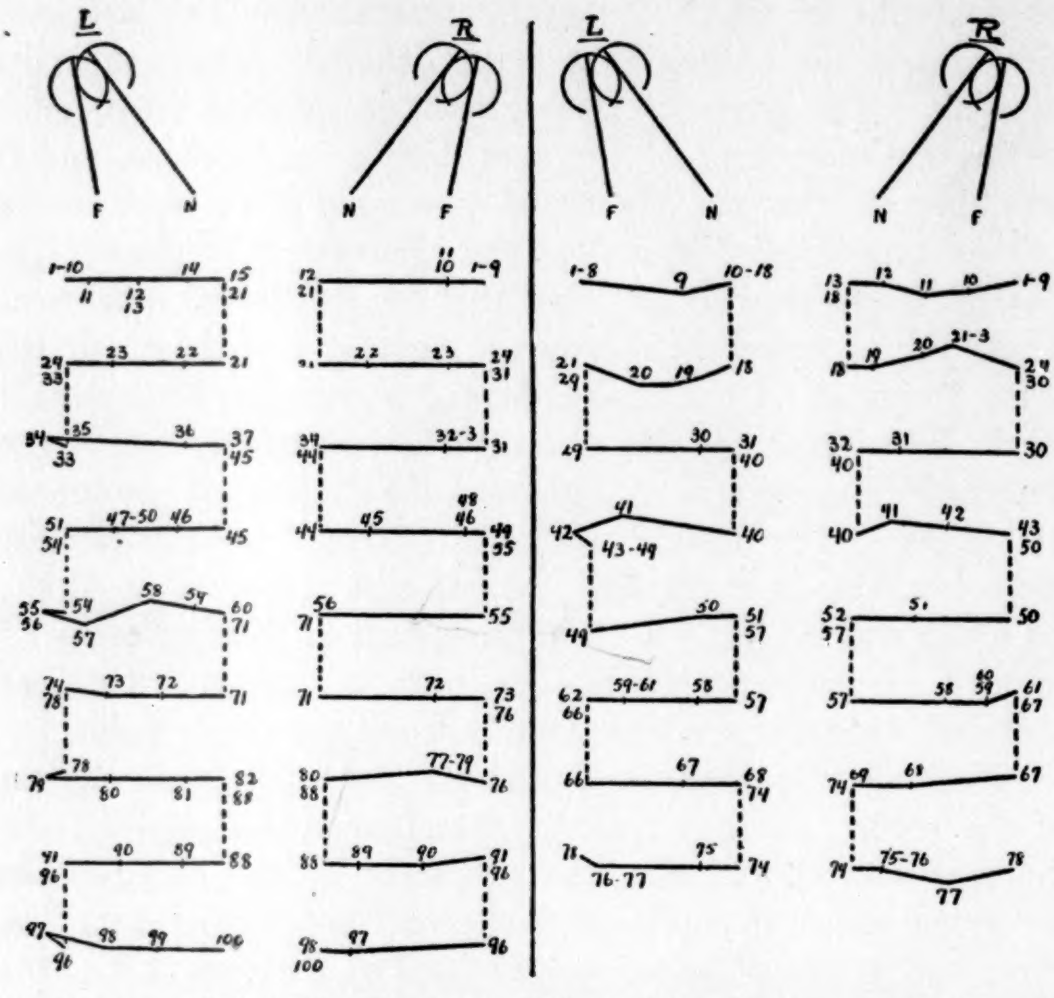


FIG. 99. Subject Mr. Kerrigan. Object of fixation two points, the more remote being at a distance of 55 cm. from the bridge of the nose, the nearer at a distance of 30 cm. The two points lie in the median plane between the two eyes. The average time of the exposure is 94σ. Individual exposures do not depart from this average by more than 3σ.

FIG. 100. Subject C. H. Judd. Points of fixation 30 and 55 cm. respectively from the bridge of the nose. The two points do not lie in the median plane but are slightly foreshortened for the left eye so that movements of the right eye are greater in extent than those for the left eye. The average time of the exposure is 97σ with a departure in individual determinations of not more than 3σ from this average.

for its complete movement from the remote point to the near point somewhat less than 300 σ. The difference is still more notable when we take the third movement of convergence.

The left eye requires from photograph 54, or at least from 56 to 60, that is, four or six photographs, while the right eye in making the corresponding movement requires only the time elapsing between photographs 55–56. The movement of the right eye in this case did not exceed 96 σ, whereas the movement in the left eye certainly did not require less than 375 σ, while if we count the lateral movement from 54–56 the time is nearer 550 σ. Furthermore, the path of the eye movement in the two eyes is shown to be different in form by the lines extending in Fig. 99 from 56 to 60. The same typical difference in the path of movement is seen by comparing the character of the movements of the two eyes between photographs 76 and 82.

This lack of harmony in the two eyes has a special character in each one of the subjects. In Fig. 99 the left eye is in general behind the right eye in all of its adjustments. In Fig. 100, on the other hand, the right eye is slower in its adjustments than the left. The contrast in these two cases is very sharp. In Fig. 101 the right eye is again somewhat more rapid in its adjustments than the left eye, while in Fig. 102 there is no marked superiority in speed of movement in either eye. If we attempt to throw further light upon this individual mode of convergence in which one eye often seems to be decidedly in the lead, we find no evidence which would go to show the relation of eye movements to right-handedness or left-handedness. The subjects of this experiment were right-handed, at least in the case of the three subjects represented in series 100–102. The subject of the photographs represented in Fig. 99 is not now accessible and the question did not arise in time to determine definitely whether or not he is right-handed. At all events, in the case of three subjects, all of whom are right-handed, there is a distinct difference in the behavior of the eyes. In the one case the left eye leads, in another the right, and in the third case there seems to be a balance between the two eyes. Nor is the eye which leads in speed of movement the eye which shows the greater acuteness of vision. The subject in Fig. 100, whose left eye is decidedly in the lead, shows less acuity of vision for the left eye than for the right. The left eye of the

subject represented in Fig. 101 is more acute in vision than the right eye, yet the left eye is slower in its adjustments. According to this very limited evidence, it would seem to be the less acute eye which makes the most rapid adjustments. The true explanation of the relation between left and right eyes is prob-

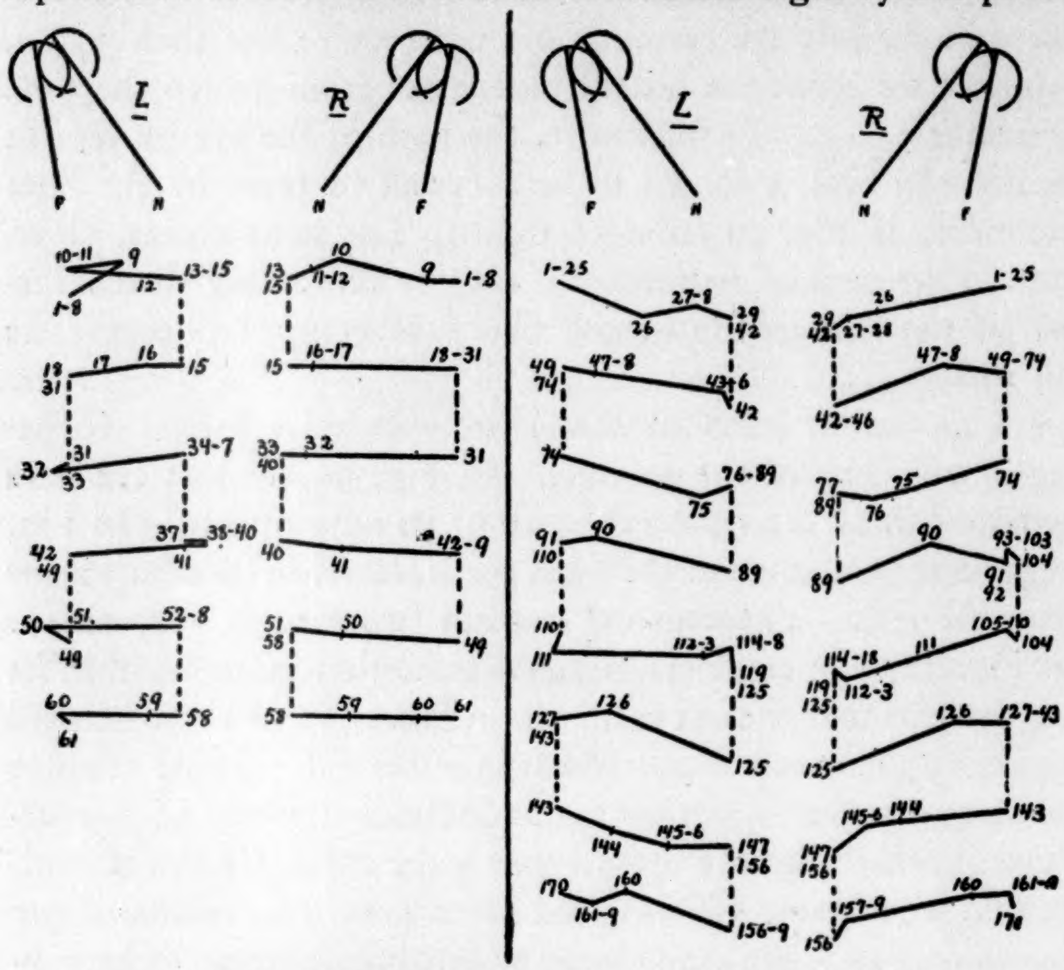


FIG. 101. Subject E. H. Cameron. Points of fixation 30 and 55 cm. respectively from the bridge of the nose. The distance for the left eye is foreshortened. The average time of exposure is 117σ with a possible variation in individual cases of 4σ.

FIG. 102. Subject C. A. Cockyane. Distance of points of fixation 30 and 55 cm. respectively. These points lie in the median plane between the two eyes. The nearer point is somewhat lower than the more remote point with the result that the eyes in converging move downward and in diverging move upward. The average time of exposure is 100σ with a variation not exceeding 3σ in individual cases.

ably to be sought in the fact that there is a difference in muscular balance in the two eyes. The fact that there is a general agreement in character of movement among the four subjects, while at the same time the subjects differ from each other radically in the matter of relation between the two eyes, would

seem to indicate that the relation between the two eyes is a wholly incidental matter. It is not essential to the consideration of binocular adjustment as is shown in Fig. 102, which is a case of almost equal balance of the two eyes. Furthermore, the special characteristics of movement in one eye or the other are more marked in general in the horizontal plane which is represented in Figs. 99–102 than in other planes. Series of photographs were taken with the subjects represented in Figs. 100 and 101, with the points of fixation placed at various angles out of the horizontal. Positions of 40° below the horizontal plane, of 15° below this plane, of 15° and 30° above were taken with each of the subjects. One of these records is reproduced for another purpose in Fig. 114. It is typical in that it shows the same general form of movement as in the horizontal. It may be stated, however, that in general extreme positions above or below tend to induce change in the relations between the eyes. Thus for the subject of Fig. 100 there is a mere uniform balancing of the movements in the two eyes than that represented in Fig. 100 for all upward movements. Otherwise the characteristics of the figures are essentially the same. This would seem to indicate as held above that differences in muscular tension are the significant factors in determining the relation of the eyes. When the eyes are turned upward the tensions are not the same as when the eyes move in a horizontal plane. Furthermore, when the balance of tension is entirely changed by bringing the objects into line with one of the eyes, the relation of the eye thus relieved of tensions of its own, to the other eye, is very marked. Cases of this kind will be discussed fully in a later paragraph and are exhibited in Fig. 103. We may sum up this part of the discussion, therefore, in the statement that the two eyes do not move to points of convergence or divergence at the same rate for most subjects nor always in similar paths, but that this lack of similarity in the movements of the two eyes is probably due to external muscular causes and not to internal nervous adjustments.

It is important to notice in connection with the recorded disparity between the movements of the two eyes that fixation is not completed for the subject's inspection until such time as

the slower eye has reached its final fixation upon the point to which attention is given. Evidence on this point was collected in the course of the experiment by giving the subject a reaction key and requiring him to press down upon the key as soon as he was satisfied that he had fixated the point nearer at hand. He continued the pressure on the key until such time as he executed a movement of divergence when he released the key. The record made by pressing and releasing the key was taken through a marker on the same strip of smoked paper as the record showing the rate of the photographs. In this way the subject's introspections with regard to his convergence and divergence were taken in parallel with the photographs showing the position of the eyes. Referring to Fig. 101, for example, the subject's reaction record shows that he was satisfied that he was looking at the near point when photograph 14 was taken. He was satisfied again that he was looking at the more remote point at photograph 20. The following introspections show the near point at photograph 34; remote point photograph 44; near point again at photograph 52; remote point at photograph 63. In all of these cases it will be observed that the reaction is slower than the final adjustment of convergence or divergence by enough to allow in each case for the reaction time of the hand after fixation had been completed. In no case does the subject make the introspective reaction before the movement of convergence or divergence of both eyes has been completed. This is typical of the introspections of all the subjects. Records of introspections were taken with the great majority of the records upon which this paper is based and there is no case in which the introspective record does not bear out this general statement.

A second general characteristic of all the movements shown in Figs. 99–100, and the other similar records mentioned above, appears in the fact that the time of convergent and divergent adjustment is relatively very long. For comparative results which do not involve convergence and divergence, reference may be made to certain photographs that will be reported in the present series and are represented in Figs. 117 and 118 of this paper. It will here be seen that the first two movements

in Fig. 117 required certainly not more than 180 σ each, and the second movement which lies between photographs 12 and 13 could not have required more than 90 σ. Similar evidence can be drawn from many of the earlier series reported in the first number of the Studies. The movements of convergence and divergence as contrasted with these simple lateral movements required a period of time which is in general 350 σ or more. Furthermore, the movements of convergence and divergence here represented show themselves to be complex and difficult in the frequent pauses which are made by the one eye or the other in passing from one point of fixation to the other. It is obvious that we have to deal here with a complex form of adjustment. This general fact can not be explained as could the lack of uniformity in the movement of the two eyes, by any reference to the external muscular structure of the eyes. The eyes are converged or diverged in such a way as to fixate definite points, and these movements involve a careful adjustment with many pauses and corrective movements which consume the long period of time required for this adjustment. The evidence is not wanting that the movements are in many cases movements of fine adjustment after the main movement has been executed. For example, in Fig. 102 movements of the left eye between 28 and 29, between 75 and 76, between 113 and 114 are all of them obviously in the nature of final corrective movements. Other examples of similar character can be seen in all of the figures. This final adjustment of the eye would seem to signify that the complete execution of a movement of convergence or divergence is in the nature of a slow and careful adjustment of the eye to a stimulus which is in some form or other recognized as not completely met by the main movements. We shall call attention in the later discussion to other evidences which go to show that the movement of convergence is under the constant direction of the stimulus and is a movement of fine and difficult adjustment.

A third fact which may be noted in certain of these figures now under discussion, but which will be very much more fully illustrated in later figures, is the fact that in some cases the eyes before they begin the careful adjustment of convergence, exe-

cute a lateral movement in which the two eyes sympathize by moving in the same direction rather than in opposite directions as required for convergence or divergence. A conspicuous illustration of this is to be found in Fig. 101 in the movement between photographs 31 and 32. After photograph 31 the right eye moves in a long sweep toward the left, thus reaching a position required for convergence. The left eye, on the other hand, instead of moving in such a way as to converge upon the nearer point, executes like the right eye a movement from right to left. This movement is directly opposed to the movement of convergence which must later be executed by this eye and it is explicable only by assuming that the left eye sympathizes automatically in its behavior with the stronger impulse of the right eye. A similar fact may be seen in Fig. 99 in the movement which lies between photographs 96 and 97. Here again the right eye executes a long movement toward the left and the left eye follows in the same direction. The tendency for the two eyes to move in the same lateral direction at the same time, rather than in the direction of convergence or divergence, seems, therefore, even in these earlier photographs to be sufficiently strong to assert itself with all clearness.

Stronger evidence of the fundamental character of this tendency to move the two eyes in the same direction comes out in a number of series of photographs taken with the objects of fixation so arranged that they lay directly in the axis of vision of one of the eyes. Two series of photographs of this kind are shown in Figs. 103 and 104. These photographs are from the subject reported also in Fig. 101. In Fig. 103 the left eye is obliged to make a movement toward the right whenever it changes its center of fixation from the remote object to the nearer object. The right eye, on the other hand, is not called upon to change its line of regard in looking from the remote object to the near object, it simply changes the degree of accommodation of the lens when it has finally reached its position of rest. It is a very striking fact that the process of adjustment in the right eye which is called upon to maintain a single line of regard, is quite as complex as the process of adjustment in the left eye which is required to make large movements of con-

vergence and divergence. Indeed, in some respects it is even more complex, and this complexity can be described very simply by the statement that whenever the left eye makes a movement of convergence or divergence there is a tendency for the right eye to follow the same path of movement as the left eye. Thus, when the left eye moves toward the right between photo-

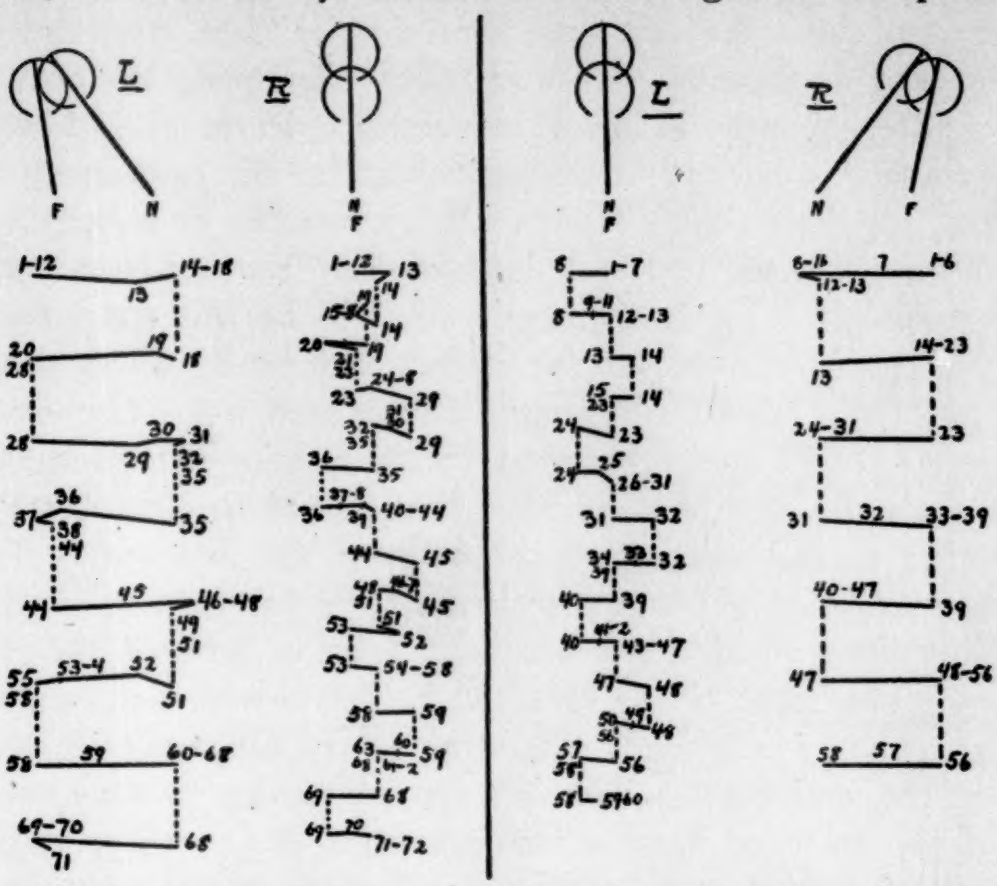


FIG. 103. Subject E. H. Cameron. The objects of fixation at 30 and 55 cm. respectively from the bridge of the nose. These points lie in the line directly in front of the right eye so that the right eye in fixating the two points is not required to move its axis laterally. The average time of exposure is 120σ with a possible deviation in individual cases of 4σ.

FIG. 104. Subject and conditions like those in Fig. 103 except that the two points of fixation here lie in the line directly in front of the left eye. Average time of exposure 124σ with a possible deviation in individual cases of 4σ.

graphs 12 and 13 the right eye also makes a movement toward the right. This movement of the right eye brings it out of line with the two points of fixation. There follow, therefore, a series of movements of readjustment, as indicated in the figure, until in photograph 15 a final fixation is reached satisfactory to the subject. It is interesting to note in this connection that the introspection of the subject showed that he regarded

the fixation as complete only after photograph 15. Continuing in the detailed examination of Fig. 103, we find that after fixating the near point for a period of time the two eyes between photographs 18 and 19 execute a slight movement of divergence. This movement of divergence showed itself in both eyes. This and other evidences throughout the figures seem to show that divergence is simpler than convergence. But even divergence gives way before the strong tendency to complete sympathy in lateral movement. In the case in hand, divergence is evidently only preliminary to the further adjustment, for there follow from 19 to 20 two like or sympathetic movements in the two eyes, both of them moving toward the extreme left. The right eye is involved by this sympathetic movement in the necessity of a secondary readjustment which is not fully accomplished until photograph 21. The introspective record shows that the subject's reaction for divergence parallels the 23d photograph. Between 28 and 29 there is another sympathetic movement between the two eyes. The readjustments which take place from 29 to 32 evidently involve a different type of the sympathetic relation between the two eyes. The right eye is involved in the necessity of moving from 31 to 32 in order to regain the natural position of fixation upon the near point. The left eye seems also to have overshot the mark of fixation between 30 and 31. It is consequently involved in a movement of readjustment. Another case of this kind of correction for the left eye seems to appear between 48 and 49.

It will be remembered that the subject of these photographs in Fig. 103 showed a natural tendency, as shown in Fig. 99, to make more rapid and independent movements with the right eye than with the left. The strong sympathetic behavior of the right eye with the left, as reported in this series of photographs in Fig. 103, is a clear indication of the fundamental and natural character of the sympathetic movement of the two eyes. The fact of sympathetic movement appears in the reverse relation in the photographs reported in Fig. 104. Here, again, the eye which is not called upon by the conditions of the experiment to execute any lateral movements, that is, in this case the

left eye is constantly involved in sympathetic adjustments in which it moves at first in the same direction as the right eye and then afterwards by a series of readjustments comes back

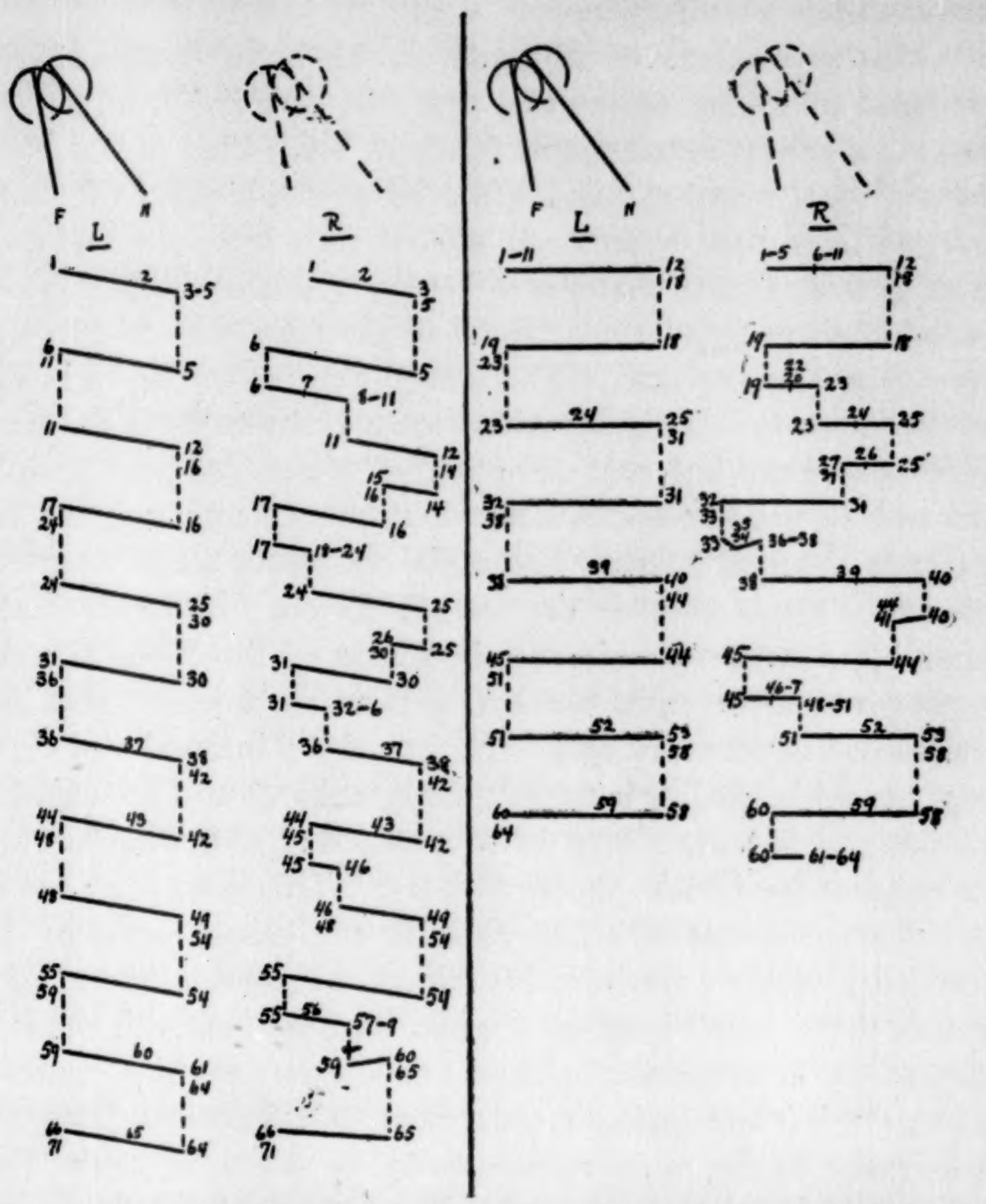


FIG. 105. Subject Mr. G. who has been for a period of years blind in the right eye. Points of fixation 50 and 25 cm. respectively in the median plane between the two eyes. The near point somewhat lower than the more remote point. Average time of exposure 104σ with a possible deviation in individual cases of 3σ.

FIG. 106. Subject same as in Fig. 105. Points of fixation 50 and 25 cm. respectively from the bridge of the nose in the primary horizontal plane. Average time of exposure 82σ with a possible deviation in individual cases of 3σ.

to the original point of fixation. Series of exactly the same type as here obtained were secured from the subject reported

in Fig. 100. The general statement here worked out in detail is also supported by earlier observations. Professor Dodge in an earlier paper on eye movements[1] referred to facts of the same sort as here described.

Further evidence of the fundamental character of this sympathetic movement of the two eyes was obtained from subject G., who, as was noted above, has been for a long period blind in one eye. Figs. 105 and 106 represent two series of photographs from this subject. It will be seen from the examination of these figures that the right eye, which is blind, does not make movements of convergence or divergence as its primary movements in any case. The first movement of the right eye always consists in a distinct and extensive movement in the same direction as the left eye. For example, between photographs 11 and 12 the left eye makes a long movement from the far point to the near point. The right eye makes a movement of about the same extent in the same direction. Not only is the lateral movement in this case in the same direction, but the movement of the right eye is downward in keeping with the movement of the left eye. After a short interval the right eye, as seen in the line between photographs 14 and 15, changes its position in such a way as to come back somewhat toward its original position in photograph 11. This it will be noticed is not a movement of convergence in any proper sense of the word, it is rather a tendency to readjust the position of the right eye so that it shall keep its original position before it made a movement in sympathy with the left eye. In like manner, when the left eye makes a movement of adjustment from the near point to the more remote point, as indicated in the line 16–17, the blind eye makes a similar movement. It later corrects this long sympathetic movement between 16 and 17 by a short movement of readjustment between 17 and 18, but here again the position 18 is not the same as the original position 16 from which it started. The final position of the right eye at any given moment seems to be more or less the accidental resultant of the accumulated tendencies of earlier sympathetic movements. The movements of the blind eye are, however,

[1] *American Journal of Physiology*, 1903, VIII., p. 328.

very clearly sympathetic movements and not movements of an independent character. The same facts appear in Fig. 106, where the blind eye shows even a more marked tendency to sympathize with the left eye. The left eye in this case executes a somewhat longer movement than in Fig. 105 and the result appears in the very long sympathetic movements in the blind eye. This is notably true between photographs 31 and 32, between photographs 38 and 40, and between photographs 44 and 45.

It is important to note in connection with these photographs of subject G. that the whole activity of convergence and divergence is reduced to a very much simpler level when it is a monocular adjustment. This is evidenced not only by the photographs exhibited in the figures, but also by the introspective testimony which was taken in parallel with the photographs. Thus, the subject reacted for complete convergence in parallel with photograph 4. Divergence was shown in parallel with photograph 7. The next convergence falls upon photograph 12, divergence on 18, convergence on 26, divergence on 33, convergence on 38, and so on through the series. It thus appears that the convergence and divergence of the subject who sees with one eye only are free from the delays which are required in the case of subjects who see binocularly, and the form of movement is at the same time very much simpler in character. There seems to be, therefore, clear evidence not only that the lateral movement is the simpler form of united action of the two eyes, but that when lateral movement is the only form of movement required the whole adjustment is simple in its character.

Further evidence with regard to the simplicity of mere lateral movement is to be derived by an examination of monocular convergence and divergence, as shown by normal subjects when a single eye has been covered up. Figs. 107 and 108 show two simple cases of convergence and divergence after covering one eye. These photographs are from the subject reported in Fig. 100, and a comparison of these figures with the results in Fig. 100 show immediately the much simpler character of the movements. The time required for the monocular adjust-

ments is relatively shorter. For example, in one case between photographs 37 and 38, the whole movement is executed in a period of time considerably less than 100 σ. By referring to the second film it was found that the eye had reached the position indicated in the figure by 38 at the time when the photograph was being taken which lies between 37 and 38. In other words, the total movement from 37 to 38 as a movement involved between 45 and 90 σ. The adjustment between 49

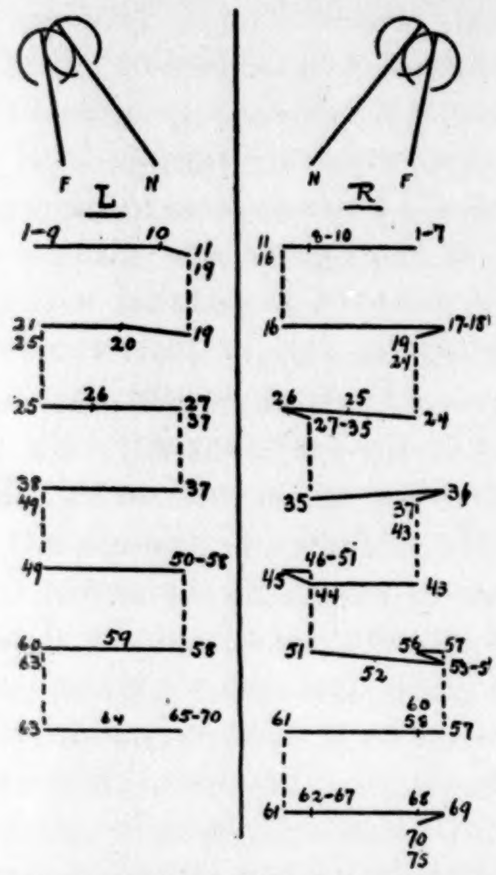


FIG. 107. Subject C. H. Judd. Points of fixation 55 and 30 cm. respectively from the eye and in a line directly in front of the nose. The right eye is entirely covered. All movements recorded in the figure are accordingly for the left eye. The average time of exposure is 94σ with a variation not exceeding 3σ for individual exposures.

FIG. 108. Subject and conditions same as for Fig. 107 with the exception that the left eye is covered and movements here recorded are for the right eye. Average time of exposure 90σ with a possible deviation of 2σ from the average.

and 50 was also sufficiently rapid so that its period can be described as distinctly below 100 σ. The introspective records of the subject show that complete divergence and convergence was secured in these two cases in parallel with the next succeeding photograph, as in most of the earlier records. There

is, therefore, obviously no delay such as is demanded in binocular convergence and divergence.

The movements of the eye in Fig. 108 show certain distinct complexities in character. These complexities may be described by the statement that when the eye is moving in a given direction there is a tendency for it to move too far in the direction in which it is traveling. Thus, between 16 and 17 in Fig. 108 there seems to be so long a movement that there is necessity for a readjustment as indicated between 18 and 19. Similar facts are shown in the readjustments between 26 and 27, between 36 and 37, between 45 and 46, between 69 and 70, and a very complicated readjustment appears between 55 and 57. The meaning of these readjustments in monocular convergence and divergence is not easy to make out. Evidently the right eye in this subject is less regular in its behavior than the left eye. This may be related to the fact that the right eye shows greater irregularity of movement in the earlier series in which both eyes are involved. The right eye in this subject, as stated above, is the eye which shows the greatest acuity of vision. It is, therefore, improbable that its less precise adjustments at the end of the movement are due to retinal conditions. It is probably true that the muscular balance of the two eyes is not the same and it is not unlikely that the pecularities of behavior are connected with these muscular inequalities rather than with the internal or retinal processes.

Collateral evidence in view of this conclusion can be offered in the case of the subject of these photographs by means of experiments discussed by the writer in a paper published in *Science,* 1898, VII., pp. 269–271. The experiments in question may be tried by covering one eye and steadily fixating a bright object with the uncovered eye. The covered eye should now be suddenly uncovered when there will appear double images which are crossed and therefore indicate that the center upon which the lines of regard of the two eyes were converged was more remote than the object fixated by the open eye. The position assumed by the eye which has been covered in this case will undoubtedly depend in part upon its own tendencies of relaxation. That the center of convergence is further than

the point of fixation would indicate that the natural tendency of relaxation in the covered eye is in the direction of a movement of divergence. The distance of the double images from each other at the moment of uncovering the eye will give some clue to the degree of divergent tendency in the covered eye. The observation of this double image requires some practice. The writer has made long series of observations with his two eyes and finds that the distance between the after-images when the right eye is covered is greater than the distance when the left eye is covered. The muscular tensions of the right eye seem from this experiment, therefore, to be somewhat more pronounced than the muscular tensions of the left eye. This result is clearly in agreement with the typical differences in the behavior of the two eyes, as shown in the photographs exhibited in Figs. 107 and 108. That the right eye should be for this subject more difficult to bring into binocular convergence and divergence, as is shown in Fig. 100, seems also to be clearly in agreement with these evidences regarding the monocular behavior of the right eye. Such considerations show the difference between binocular and monocular adjustments and at the same time show also their intimate interrelation. Monocular peculiarities constitute the negative tendencies which must be overcome in order that binocular adjustments may be accomplished. Binocular adjustment is therefore a complex process in which monocular tendencies and tendencies toward lateral sympathetic movements must be replaced by a more elaborate form of coördination.

The simplicity of adjustment in monocular vision can be further attested by means of the series of photographs from another subject, as reported in Figs. 109 and 110. In these two series the camera was set in motion before the eye which was not to be used in the full series was covered. The result is that the first movements are binocular. The binocular movements here reported did not continue long enough to give very full evidence, but the second binocular movement in Fig. 109 agrees with all the other records from this subject, as for example, those reported in Fig. 101. In considering the first movements in Figs. 109 and 110 it should be recognized that the first

movement often differs from the later movements. At all events there can be no ambiguity regarding the character of the monocular movements of this subject. Though they consist of adjustments to near and remote points they are ex-

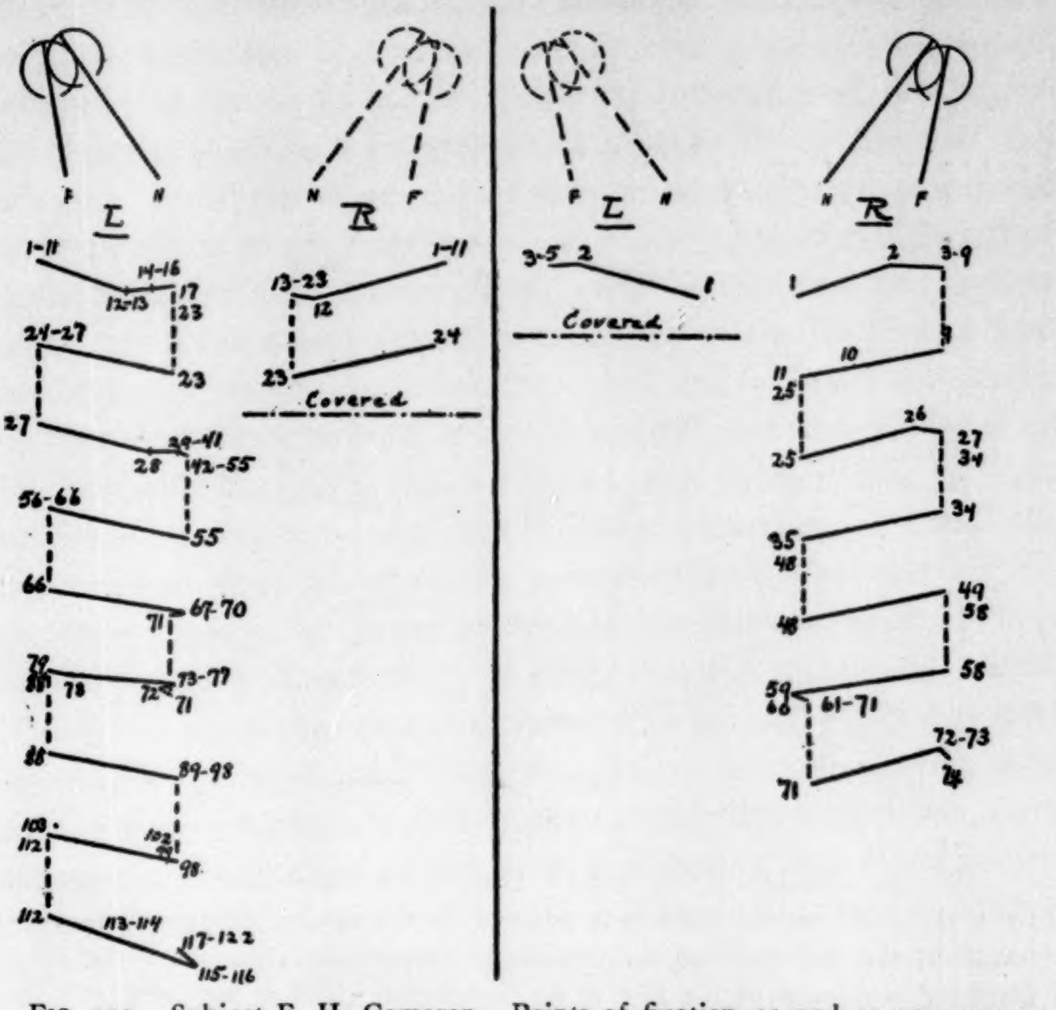


FIG. 109. Subject E. H. Cameron. Points of fixation 55 and 30 cm. respectively in the median plane between the two eyes. The axes of vision are directed upward in looking at the more remote point and somewhat lower in looking at the near point. After twenty-six exposures the right eye was covered so that the remainder of the record shows the movement of the left eye only. The average time of exposures 75σ with a possible deviation in individual cases of 2σ.

FIG. 110. Subject and conditions the same as Fig. 109 with the exception that the left eye was covered in this case as indicated in the figure after five exposures. Average time of exposures 75σ with a possible deviation in individual cases of 2σ.

tremely simple and in striking contrast with the binocular adjustments of the same subject as reported in Figs. 101 and 114.

One special case of monocular adjustment which is of crucial importance for experimentation with monocular vision may

be investigated by the methods here employed. If two points are placed in a direct line in front of one eye, and the second eye is covered so as to be entirely excluded from participation in vision so far as retinal factors are concerned, it is found that the open eye is involved in certain adjustments which suggest

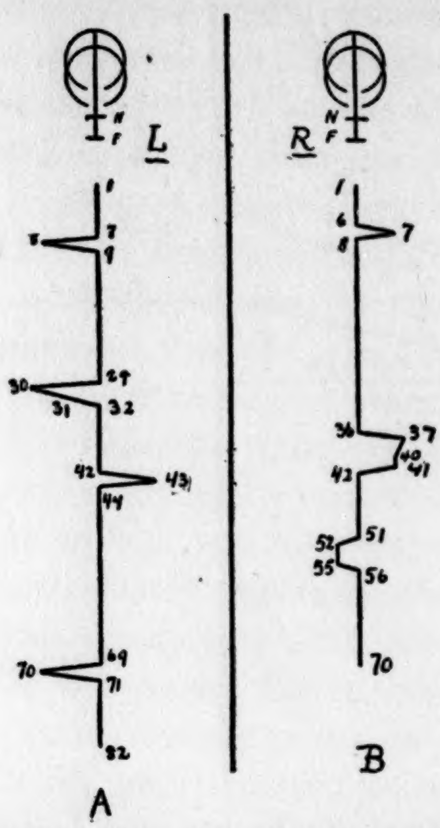


FIG. 111. Subject C. H. Judd. This figure represents the eye movements by a different method from that adopted in the earlier figures. The vertical length of the line indicates the number of exposures. Thus, in *A* the distance from the beginning of the line to the movement which is indicated at 7 is on the same scale as the distance from 9 to 29 which represents a continuous fixation of the eye at one point during 21 exposures. Slight movements of the eye about the point of fixation are neglected in this figure. *A* indicates the form of motion for the left eye, *B* the form of motion for the right eye when the two points of fixation lie in the direct line of the visual axis of the open eye, the right eye being covered while the photographs were being taken for the left eye, and the left eye being covered while the photographs were being taken for the right eye. The average time of exposure for both *A* and *B* was 96σ with a possible variation in individual cases of 2σ.

the continued participation of the covered eye in the movement of convergence and divergence. The conditions here under discussion are related to those which are presented in Figs. 103 and 104. It was there found that the eye which was not required to make any lateral movement in fixating near and remote

points did, nevertheless, by virtue of its sympathetic relation with the eye that was involved in elaborate lateral movements, execute certain unnecessary sympathetic movements and certain supplementary movements of readjustment. In Fig. 111 two series of photographs are reported which deal with this case which has often been assumed by experimenters to be a case of pure monocular vision. In the series of photographs represented in *A* the right eye was entirely covered and the points for fixation were so arranged as to lie directly in front of the left eye. The introspections of the subject show that at a point corresponding to photograph 10 the subject was satisfied that he had fixated the nearer point. The fixation of the nearer point called for no movement whatsoever of the left eye. The two movements which lie between 7, 8 and 9 must, therefore, be explained as a sympathetic movement and a movement of readjustment. The right eye which was in this case entirely covered up undoubtedly made some movement. That the covered eye does not cease its movements in binocular adjustments can easily be demonstrated by laying the finger lightly on the lid of a closed eye and observing the movement of the closed eye when the open eye changes its fixation from a remote to a near point or the converse. The normal subject who makes this observation will discover that the closed eye tends to converge and diverge not as in the case of the blind subject reported in Figs. 105 and 106, but rather in a way similar to that reported in Figs. 103 and 104. In the case in hand the covered right eye undoubtedly executed a movement from right to left while the left eye was making its movement in the same direction from 7 to 8. The left eye then made a rapid adjustment from 8 to 9, while the right eye continued its movement of convergence.

A similar case appears in the figure in the movement and adjustment between 29 and 32. Here the subject's introspections show that the satisfactory fixation of the near point coincides with photograph 32. A sympathetic movement of divergence with the corresponding introspective evidence appears between 42 and 44. These photographs show with all clearness that the covered eye is by no means eliminated from con-

sideration when an adjustment from a remote to a near point is under discussion. These facts constitute a fatal objection to the methods and results which have become classic in psychology for experimentation on monocular accommodation. Among recent investigators, Arrer, Hillebrandt, Baird and others have placed the objects of fixation exactly as they were placed in this series of photographs in a direct line in front of the open eye. They have covered or closed the other eye and proceeded with their investigation on the assumption that they had eliminated binocular influences, at least in major part. All that they have eliminated in such cases are the retinal images involved. There is a very large influence, as shown in these photographs, so far as the movements of convergence and divergence are concerned. Furthermore, the effects on the behavior of the open eye are by no means uniform either in character or in mode of occurrence. For example, it is seen in Fig. 111 by contrasting the behavior of the right and left eyes of the same subject under similar conditions, first, that the movements of the left eye are more extensive than those of the right eye, while adjustments are in general very much more rapid. The readjustments in the case of the right eye are so slow that in some cases, as for example between 36 and 42, a period comparable to the period ordinarily required for convergence is involved. That different subjects would probably differ in the extent to which the closed eye influenced the open eye is indirectly evidenced by the fact that the blind subject in whom one eye had long been disused made very irregular movements with what in his case corresponded to the covered eye. In his case the blind eye was almost completely dominated by the tendencies of movement in the normal eye. It is probably true in certain subjects that one eye is much more independent than in others. There may be individuals for whom the control of normal vision is sufficiently strong to dominate the whole movement. Indeed, there were in the case reported in Fig. 111, between photograph 8 and photograph 36, three movements, two of divergence and one of convergence, for which there is absolutely no evidence of any readjustment in the open eye. This itself is sufficient evidence that the influ-

ence of the covered eye is somewhat irregular in character. In some cases apparently the open eye dominates, in others there is a clear domination of the covered eye. The net result is that the binocular influence not only is not withdrawn, but it is complicated in an unknown fashion by the various tendencies

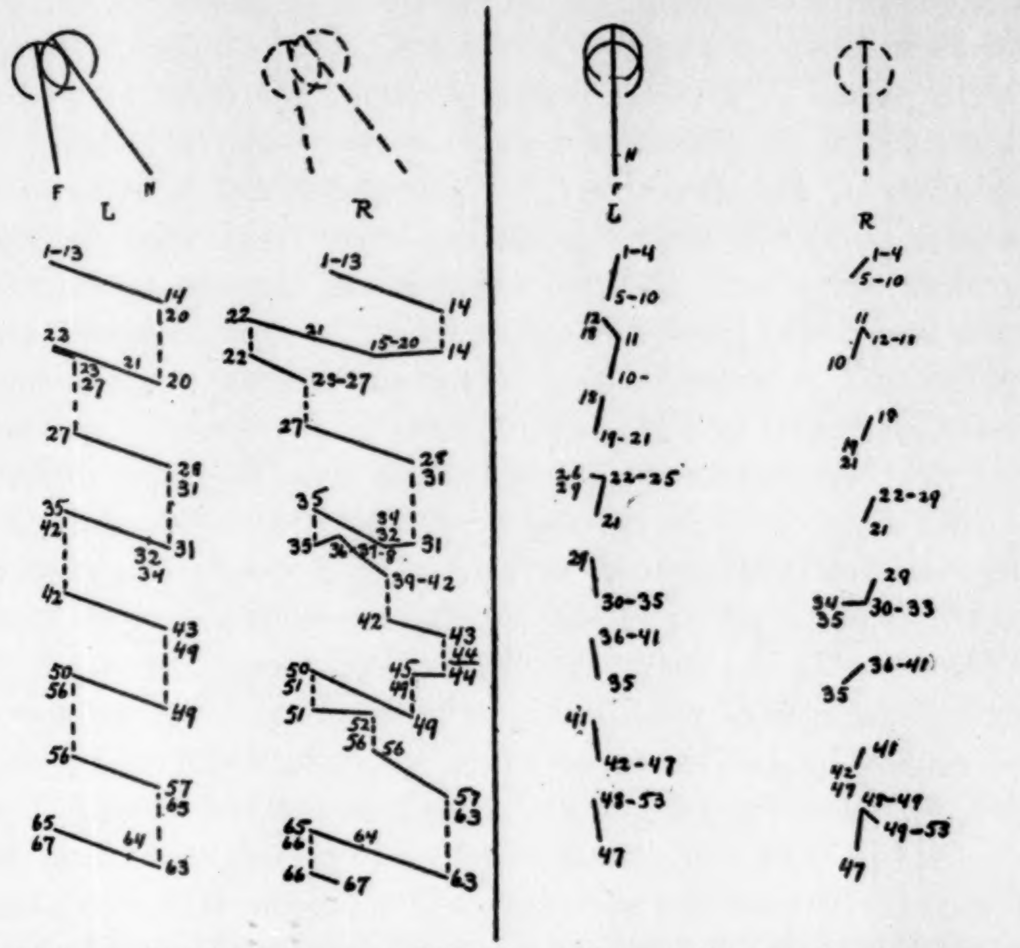


FIG. 112. Subject same as in Fig. 105. Distance of points from the eye 50 and 25 cm. respectively. Points placed in a line directly in front of the right eye such that if the eye were capable of vision the points would lie in the line of fixation of the right eye. Average time of exposures 73σ with a possible deviation in individual cases of 3σ.

FIG. 113. Subject as in Fig. 105. Points of fixation 50 and 25 cm. respectively in front of the bridge of the nose. These points were placed in the line of fixation of the left eye. Average time of exposures 76σ with a possible deviation in individual cases of 3σ.

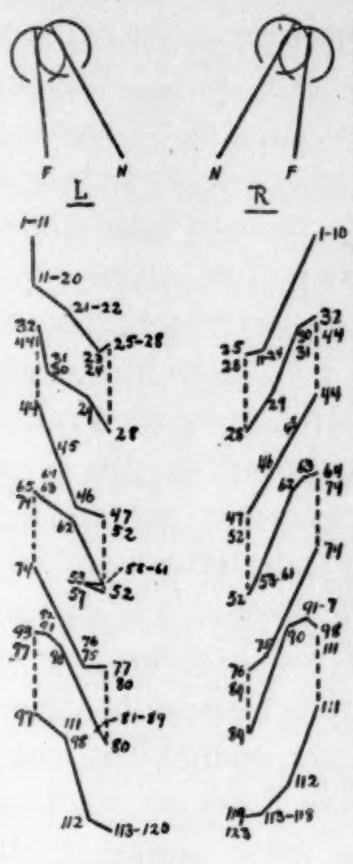
which produce in the open eye movements which are wholly uncalled for by the demands made upon that eye considered by itself. The reason why no conclusive evidence as to the character of monocular vision has ever been derived from the experiments of Arrer, Hillebrandt and others becomes per-

fectly obvious in the presence of these facts. If any method of experimentation with monocular vision is ever to be devised it must be recognized as a fundamental fact that monocular vision is not produced by simply covering one eye.

In order to test this matter with the blind subject, the conditions were so arranged in the series of photographs reported in Figs. 112 and 113 that in the one case the points of fixation were placed in a direct line in front of the blind eye, in the second case the points of fixation were placed in a direct line in front of the normal eye. Unfortunately in both cases the nearer point was placed somewhat lower down than the more remote point, with the result that an adjustment upward and downward was involved in the change of fixation between the points. The overwhelming importance of the normal eye is clearly attested in Fig. 112. There is one interesting case in which movement 22–23 seems to show some lingering influence of the blind eye. In moving from 21 to 22 there seems to be an excessive movement in the case of both eyes. The recovery in the same direction in both eyes seems to follow in 22 to 23. Whether this is a mere accident of adjustment in the left eye or a direct case of relationship of movement in the two eyes is, of course, impossible to say; it is certainly not a typical fact, for it does not appear in the other parts of the series.

In Fig. 113 there is exhibited up to photograph 30 a close sympathy between the two eyes. There is one exception to this sympathy, namely, between 11 and 12, where the blind eye moves downward at the same time that the normal eye moves upward. There is also a readjustment in the normal eye between 25 and 26, after which there seems to be a great uniformity in the behavior of the normal eye. This uniformity in behavior of the normal eye follows upon a series of readjustments prior to photograph 26, which readjustment may indicate that the subject was selecting the method of fixating the objects at which he was to look. At all events there is a difference between the adjustments above photograph 26 and below. There is in the series of photographs for the blind eye also a radical readjustment between 30 and 34. This readjustment seems to have no related fact in the behavior of

the normal eye. Furthermore, the activity of the blind eye never becomes, as does the activity of the normal eye, regular in direction and extent. There is the greatest possible irregularity exhibited in the case of the blind eye. If these photographs justify any conclusion with regard to normal vision, those conclusions seem to be in support of the general conten-



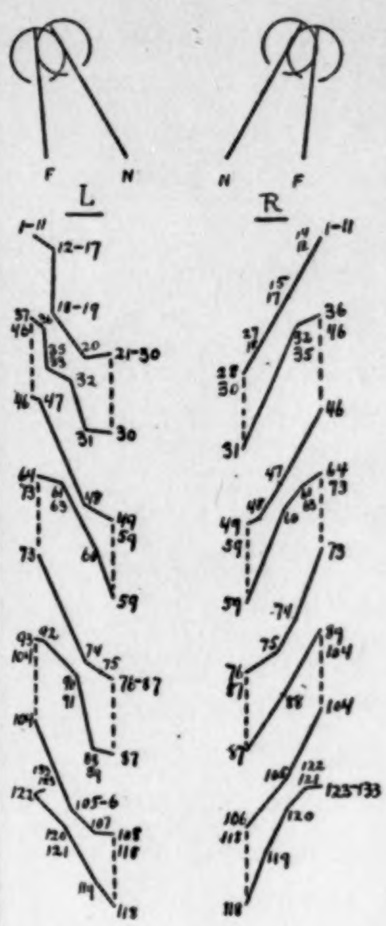


FIG. 114. Subject E. H. Cameron. Points of fixation 55 and 30 cm. from the bridge of the nose, the more remote point being much higher than the nearer point. Average time of exposures 73σ with a possible deviation in individual cases of 2σ.

FIG. 115. Subject and conditions the same as in Fig. 114. The series of photographs here reported were taken one year and three months later than the photographs reported in Fig. . The average time is 75σ with a possible deviation in individual cases of 2σ.

tion that the eye which is not guided in its behavior by retinal images is extremely irregular in its activities. So far as the criticism of the methods of monocular experimentation are concerned this figure supports the general contention that the influence of the closed eye is extremely irregular.

Returning from the discussion of monocular movements to other cases of binocular adjustment, Figs. 114 and 115 report in detail the results of two series of photographs in which the convergence on the near point was accompanied by a very pronounced downward movement of the eyes. It will be seen by examining these figures that the adjustments were fairly well balanced on the two sides in point of time, although in general as in the earlier series for this subject the right eye is somewhat more rapid in its adjustments than the left. This appears in Fig. 114 in the movement between 74 and 77 and in Fig. 115 in the movements between 87 and 93, and 104 and 108. There are, however, one or two cases in which the left eye seems to be somewhat in advance. The series are reported here not so much for the sake of reiterating the statements made in the series reported in Fig. 101, as rather for the sake of calling attention to certain characteristics of the eye movements which show the difficulty of securing photographs of monocular movements that are significant without reference to the behavior of the other eye even when both eyes are open. There is a very obvious case in Fig. 114, between 89 and 98, and another in Fig. 115, between 59 and 64, in which divergent movements of the two eyes are made up of two essentially different components: first, of a general oblique component, and second, of a horizontal component which must be explained as a corrective movement to effect a more complete divergence than was attained in the oblique movements. There are a number of other cases in the figures here reported where the eye movement is of the same general type on one side but not on the other. Thus, in Fig. 114 the movement of the right eye between 52 and 64 is of the form under discussion, whereas the corresponding movement for the left eye is of a much more complicated character. The same is true in Fig. 115 when we compare the movements of the right eye between 31 and 36 and the corresponding movements of the left eye. Furthermore, it will be seen by considering the movements of convergence reported in Figs. 114 and 115 that there is a reversal in the form of movement in that the horizontal component of the movement occurs at the bottom of the line

rather than at the upper end. Thus, it will be seen in Fig. 114 that the movement between 74 and 77 is a direct reversal in all essential respects of the movement which immediately follows it between 89 and 98. The movement of the left eye between 44 and 47 in Fig. 114 is of the same type. In Fig. 115 the movement between 73 and 76 and again the movement between 104 and 108 show the typical form of a final sharp change in the direction of the general movement. When these final adjustments in the movement are related to the whole system of binocular adjustments rather than considered merely as forms of curvature of the eye movement, it will immediately be seen that they constitute finer corrective adjustments of the eye by which it fixates the final point upon which both eyes are to converge or diverge. In other words, the form of the movement is a form of adjustment not a type of natural muscular direction of monocular movement. When the final point of fixation is in the main above or below, there will be a general movement of the eye upward or downward and a finer adjustment which is more nearly in a horizontal plane. We may regard the upward or downward components of these movements as simple sympathetic forms of movement. Since there is a strong tendency for the two eyes to move together they do not reach immediately their respective positions of fixation, but make an error which is always explicable by the principle of sympathetic movement of the two eyes.

Furthermore, the results exhibited in Figs. 114 and 115 show certain cases in which the simple adjustment described above did not appear. Indeed, there were cases to which we may call attention in which the curvature was in the opposite direction. For example, a clear case of irregular movement appears in Fig. 114 in the case of the left eye between photographs 28 and 32. The corresponding movement for the right eye conforms very clearly to the type described above as typical, but the movements of the other eye correspond more nearly to the movement which would ordinarily appear in convergent movements. In Fig. 115 the same general irregularity is to be observed in the movements of the left eye between photographs 11 and 21 and also between photographs 30 and 37. A slight

irregularity which throws the whole curve into some confusion is also to be found in Fig. 115 for the left eye, between 87 and 93. Furthermore, there are in the two figures two movements for the right eye which are as nearly straight as possible. In Fig. 114 there is a straight movement between 44 and 47. In Fig. 115 the same form of movement appears between photograph 11 and photograph 28. Indeed, attention may be called to the fact in this figure as in the earlier figures for the same subject that all of the movements of the right eye seem to show a somewhat greater regularity and precision than do the movements for the left eye. We may, therefore, conclude on the basis of these figures that all monocular movements are merely exhibitions of the complex adjustments necessary in bringing the eyes into harmonious fixation. It may be added that the figure here reported for one subject is entirely like in essential character figures obtained from two other subjects also.

A final series of facts to be reported were obtained by photographing the eyes during voluntary convergence and divergence in the effort to fuse stereoscopically two separate points without the aid of any stereoscopic apparatus. Two points were drawn on a plane sheet of paper and the subject was asked to look first at one point with both eyes and then at the other, and finally by voluntary convergence to so cross the optical axes that the left eye should fixate the right-hand point and the right eye should fixate the left-hand point. The result would be the familiar fusion of double images in such a way that three points would be seen; one resulting from the fusion of the two figures in the two eyes and the other two from the monocular effects of the two points in the two eyes.

For this experiment two subjects were available, one of whom, the writer, has long been familiar with this form of adjustment of the eyes and performs it readily and without strain, the other subject is unable to make the adjustment readily. After a good deal of effort he is at times able to bring about the fusion for brief intervals, but it is likely to be lost immediately and it can be secured only by strenuous effort. Fig. 116 reports the results for the subject who is not easily able to make the adjustment. The form of the figure is some-

what different from that which has been used in the earlier figures except in Fig. 111. A continuous vertical line such as that between 5 and 20 indicates that the eye continued for the whole period to fixate a single point. From 20 to 21 both eyes move together toward the left, from 22 to 23 both eyes move together toward the right and so on. It will be noticed by

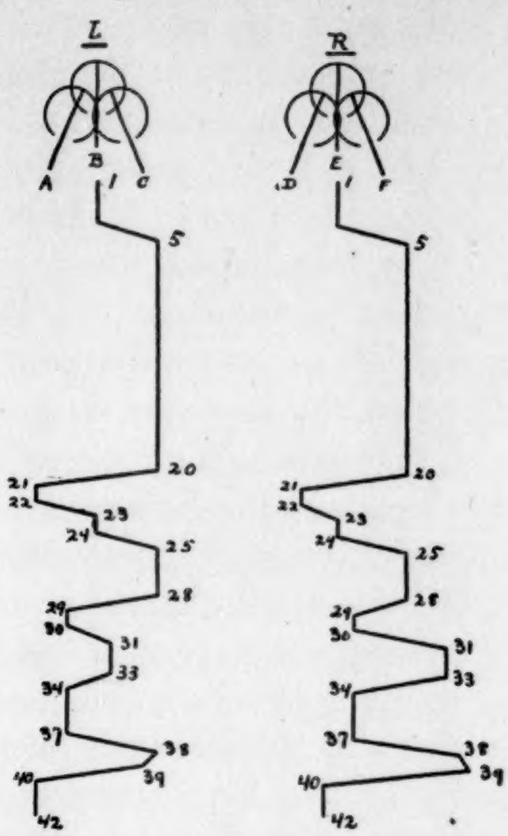


FIG. 116. Subject E. H. Cameron. Two points at a distance of 10 cm. from each other placed at a distance of 45 cm. from the eye are to be fused by a voluntary crossing of the optical axes of the two eyes such that the left eye will fixate the point on the right and the right eye will fixate the point on the left. The successive efforts of the subject to accomplish this voluntary fixation are reported in the figure, the vertical dimensions of the figure being such that distances between exposures are represented by proportionate lengths of vertical lines. Average time of exposures 70σ with a possible deviation in individual cases of 2σ.

considering the length of these various movements that the left eye moves, for example, in the movement 20 to 21 through a greater extent than does the right eye. Conversely, between 30 and 31 the left eye moves much less than does the right eye. There is only one point in the whole series at which the two eyes differ from each other in the direction of their movement, that is, between the photographs 38 and 39, and this is

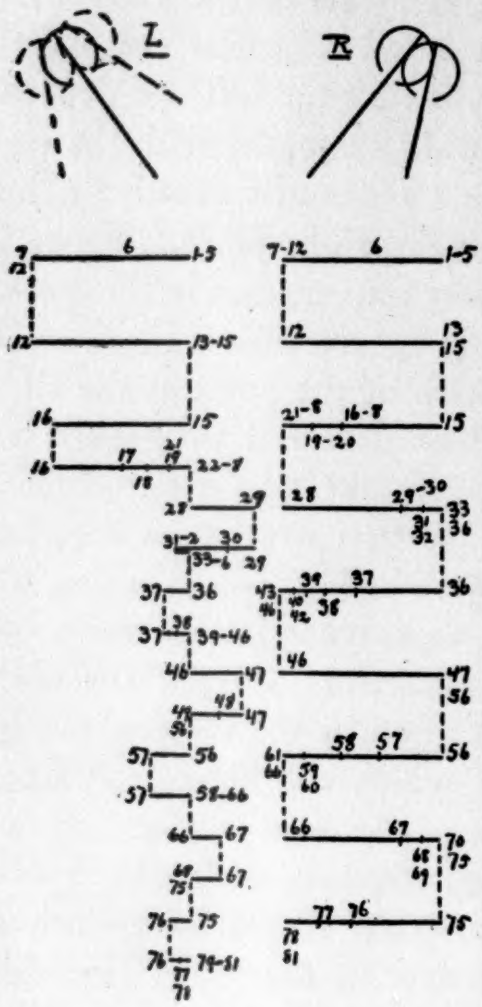
immediately corrected by a movement of the right eye between 39 and 40 much greater in its extent than the corresponding movement of the left eye. The whole figure shows clearly the difficulty experienced by the subject in attempting to bring about any voluntary convergence of the two eyes. He evidently was dominated throughout these movements by the natural tendency to move both eyes in the same horizontal direction. There is some evidence from the position of the successive points of fixation that he attempted to find a point somewhere between the two objective points given him, and this effort to find an intermediate point is doubtless to be interpreted as his effort to bring about some adjustment which should be a compromise between the two leading tendencies to fixate the right and left points respectively. There is some promise, in the fact that the two eyes do not make the same length of movement, that he would ultimately attain the adjustment necessary to bring about the fusion of the double images. Unfortunately the series of photographs was not continued long enough to record this result, but the accidental separation of the two eyes by moving one more than the other is evidently a suitable means of bringing about the final fusion of the points. This doubtless explains why the subject in question is unable to hold the point steadily for any long period of time.

Fig. 117 represents a series of movements of voluntary convergence by the writer who, as pointed out a moment ago, is capable of making this movement without serious difficulty. Between 5 and 7 the two eyes move from the point at the right to the point at the left. Between 12 and 13 the two eyes come back again to the original point of fixation. The next movement is the first effort at voluntary convergence and it will be noticed that there is a marked sympathetic behavior, both eyes moving toward the left between 15 and 16. The right eye now continues its movement toward the left until it succeeds in fixating the point at the left. This is accomplished in photograph 21. The left eye, on the other hand, by a succession of movements between 16 and 22 gradually comes back to the position which it originally held at 15. The left eye thus returns to the fixation of the right-hand point. Indeed, there

was no reason so far as the physical relations of the fovea and the right-hand spot were concerned for any movement whatsoever of the left eye when the voluntary convergence began. There was, however, in keeping with all of the facts which have been reported in the earlier cases, a definite sympathetic tendency between the two eyes such that the left eye departed from its fixation of the right point in sympathy with the right eye and was then obliged to make a series of corrective adjustments until it should again fixate the right point. From 22 to 28 the eyes were held in voluntary convergence in the crossed position attained by the preceding movements. From 28 to 29 there was a return to the fixation of the point at the right-hand side. Here, again, it will be observed that there is a strong sympathetic tendency between the two eyes. Indeed, the behavior is exactly analogous to that which was described in connection with the series reported in Fig. 104. In Fig. 104 the left eye was, so far as the objective relations were concerned, under no necessity of movement. It was, therefore, more than in any other case dominated by the sympathetic impulse to move with the right eye, which was objectively under the necessity of long movements. The rest of Fig. 117 will be easily understood after the descriptions which have been given. One notices, furthermore, that the tendency toward sympathetic action decreases in extent as the subject increases in experience with this particular adjustment. It is a familiar observation to anyone who has performed these movements of voluntary convergence that the successive efforts to fuse two given objects are less and less difficult until fatigue sets in. The photographs in this series were not continued long enough to show any marked effects of fatigue.

Fig. 118 represents a series of efforts on the part of the subject to fuse two points by divergent movements. For this purpose the two points must be somewhat nearer than the two points in the earlier experiment in voluntary convergence. Indeed, the two points upon which the subject is to voluntarily diverge the optical axes can not be further apart than the pupils of the two eyes. The whole figure was in this case held somewhat nearer to the face, with the result that the amplitude of

the movement from one point to the other is approximately the same as the amplitude of movement in the case of voluntary convergence. The movements of voluntary divergence



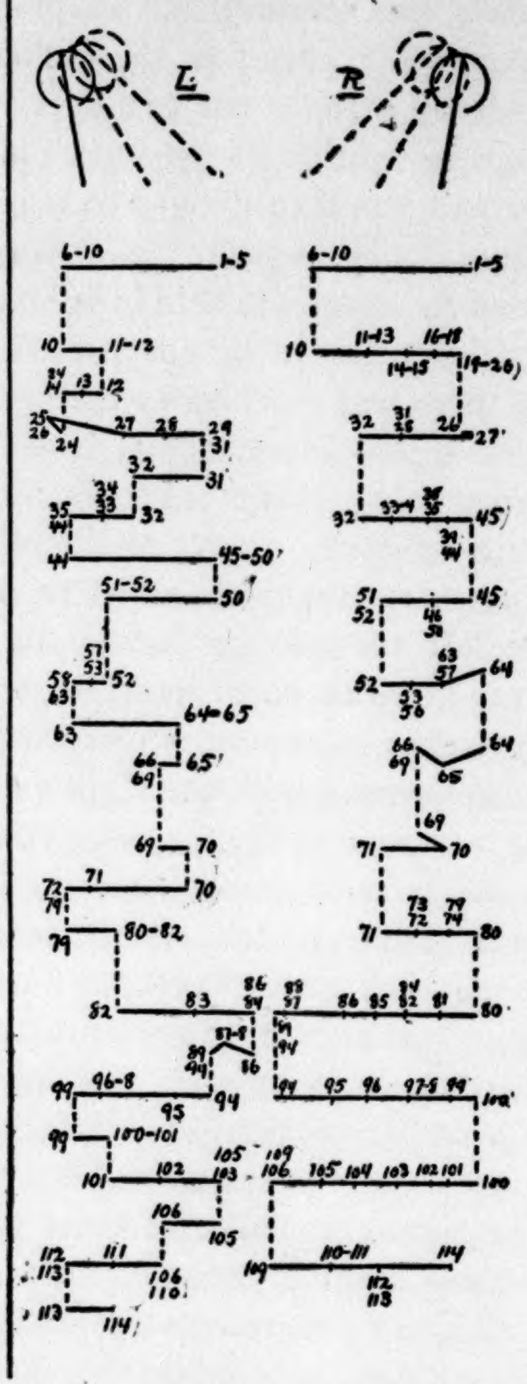


FIG. 117. Subject C. H. Judd. Showing voluntary convergence such as to fuse two points 10 cm. apart, situated at a distance of 50 cm. The first two movements reported in this figure are lateral movements from one point to the other without any effort at convergence. Average time of exposure 89σ with a possible deviation in individual cases of 3σ.

FIG. 118. Voluntary divergence in the effort to fuse two points held at a distance of 35 cm. and separated by a distance of 5.5 cm. Average time of exposure 92σ with a possible deviation in individual cases of 3σ. Subject C. H. Judd.

are always more difficult for the writer than movements of voluntary convergence. This statement hardly needs to be made in view of the clear evidence to this effect which appears in the series of photographs. The final position of the eyes in this case when fusion has been attained should be for the right eye the position occupied in photograph 5, or at least approximately in this general position, while the left eye should correspondingly occupy a position of fixation corresponding to that held in photograph 4. It will be observed that in 14, 35, 58, 72, 99 and 112 the left eye is in such a position as to indicate fixation of the left-hand point. The right eye is in a position which indicates fixation of the right-hand point at 27, 45, 64, 80, 100. Obviously the center of fixation for the right eye must be regarded for practical purposes of fusion as lying somewhat further to the left than these particular positions which have just been recorded, for the eye does not continue at 27, 45, etc., for a sufficiently long period to give the opportunity for definite fusion. Positions 19, 39, 57, 97 and 114 are maintained for a longer period and would seem to constitute the positions of relatively permanent fixation. There is obviously also some tendency for the left eye to fixate permanently the region which lies somewhat to the right of the positions corresponding to position 6. It would, therefore, seem to be true that in voluntary divergence the optical axes are not brought into a position of direct fixation upon the point, but the eyes are so adjusted that the points to be fused fall approximately at the centers of vision, though in reality somewhat at one side. This confirms the general results reported throughout the earlier investigations of eye movements both in the Yale Studies and in the paper of Dr. Dearborne,[1] where it is shown that there is no definite center of fixation, but a somewhat extended area which is entirely satisfactory to a subject.

There are a number of other characteristics in Fig. 118 which are worthy of special mention. Numerous evidences of sympathetic tendencies of movement in the two eyes are apparent. Thus, between 10 and 11 both eyes move toward the right. The left eye then returns to its original point of fixa-

[1] *Columbia Archives of Psychology,* No. 4, 1906.

tion between 12 and 14, while the right eye by a series of stages comes to the fixation of the right-hand point at 19. Again, between 50 and 51 both eyes move toward the left between 52 and 58; the left eye continues in this movement toward the left, while the right eye by a series of stages returns to a position of fixation at the right in photograph 57.

There are in the later part of the figure two curious examples of the difficulty sometimes observed in making movements of voluntary divergence. It will be seen that between 82 and 84 both eyes converge very notably. The same is true between 100 and 106. The movement of voluntary convergence, as indicated above, is easier and more fully developed than the movements for voluntary divergence. Consequently, when two points are presented to the subject there is a tendency at times to execute the movement of convergence even when the movement of divergence is intended. Indeed, it is frequently true that when the observer intends to secure fusion by voluntary divergence he secures fusion which ultimately proves to be fusion by convergence, although he may be for the moment quite unconscious of the failure to diverge and the actual fact of convergence. This reversal of the movement may also be connected with the fact that the eyes were becoming somewhat fatigued after the earlier series of efforts at voluntary divergence.

It remains in referring to the photographs to call attention to one or two general characteristics which appear in a number of the different plates. The first few adjustments of the eyes are very frequently different in character from the later adjustments. This has already been pointed out in connection with Fig. 117, where the sympathetic movement was very marked between photographs 15 and 16. In Fig. 115 it will be observed that the movements toward the end are more regular in character than those at the beginning. In series 113 a very radical change in the character of the movements appears. In Fig. 101 a good illustration appears of a very radical readjustment at the beginning of the movement of the left eye. These instances tend to confirm the statement made in the first reports of this method of photographing the eyes, that it is very desir-

able for the movements of the eyes to be recorded through more than one adjustment. A single adjustment is very likely to consist in a mere preparation for the later activities, which often become very much more regular in character after the first preliminary adjustments.

The second general fact is that in all of these adjustments there is a tendency for one or the other eye to depart either for a single photograph or for a short series from the direct line of movement. This is illustrated in Fig. 118 at photograph 64 and again in photographs 87 and 88. The same general tendency appears in the case of subject G in Fig. 112, photograph 36. Photograph 26 in Fig. 110 is another illustration of the same type. Photograph 36 in Fig. 103, in Fig. 102 photographs 47, 90 and 126 for the right eye show these same general characteristics. These departures of the eyes from the definite line of movement, especially in a vertical direction, are probably to be explained as due to muscular tensions in the superior and inferior muscles. They are not essentially different in character from the slight readjustments necessary in the lateral directions; they appear, however, somewhat more irregular because the main tendency of movement in all of these cases is in the horizontal rather than in the vertical directions.

The relation between the eye movements reported in this paper and the processes of perception to which these eye movements are related can not be defined in any simple formula of sensations of movement. It is perfectly evident that the binocular fusion of figures which is attained through the completion of movements of convergence and divergence is a process which involves much readjustment of natural tendencies toward sympathetic lateral movements. The evidence has been presented in sufficient fullness to make it clear that there are certain natural individual tendencies of movement in the eyes of different persons, and certain forms of behavior simpler than convergence and divergence, which tend to creep in during any series of fixations of near and remote objects. These irregularities of eye movement, as we may very properly call them from the point of view of completed convergence, are

seldom if ever presented to normal consciousness and certainly do not constitute positive contributions to the perceptual process. Indeed, it is necessary for us to assume that perception consists in some process which overcomes these irregularities in convergence. There must be some guiding motive which brings together the two eyes in spite of their tendencies to follow forms of movement which are simpler than those required for successful convergence.

This superior motive which stands above eye movements and controls them is certainly not explicit intention on the part of the observer to direct the eyes in their action, nor is it an explicit recognition of any irregularities after these irregular movements have been executed. One can by careful attention to his visual experiences become more or less clearly conscious of the fact that an elaborate adjustment is required for perfect recognition of objects upon which the gaze is fixated. Professor Dodge has made the very keen observation that there is always a period of what he calls 'clearing up' whenever a visual object is fixated. A little practice makes it possible for any one to observe this period of 'clearing up,' especially if the visual adjustment is from a remote to a near object. The recognition of such a clearing up period is as explicit a perceptual recognition of irregularities in eye movement as one is likely to attain. What the clearing up process actually consists in or what are the irregularities in eye movement which precede it no one can describe through his introspective observations. This is evidenced by the fact that though a great variety of observers have attempted to deal with the problem of binocular adjustment in movements of convergence and divergence, their observations are relatively incomplete as compared with the photographic evidence which can be secured in objective study of these adjustments.

The lack of explicit consciousness of eye movements that shows itself in lack of recognition of the irregularities in these movements which are present in obedience to the sympathetic tendencies of the two eyes, argues for a lack of direct relationship between visual perception and sensations of eye movements. It may be said by the defenders of the eye movement

theory that it shows merely the impossibility of analyzing movement sensations out of the total complex of visual perception. The sensations are present, these defenders will hold, and are of cardinal importance in determining the recognition of position, but their importance is not in their own specific quality and intensity, but rather in their relation to the other factors involved. In answering such a statement it can be pointed out that many of the phases of movement are in direct opposition to the whole process of convergent and divergent fixation. The eye movements not only are not analyzed out of the total situation, but many of them are in direct opposition to the character of adjustment which the subject is aiming to attain. Furthermore, they are not only in opposition to the binocular adjustment, but they are of a distinctly lower order than the binocular adjustment itself. These evidences go to show, in spite of all that has been written with regard to the sensations that result from these movements and especially with regard to the tensions toward movements which are frequently regarded by the defenders of the movement sensation theory as of greater importance than the movements themselves, that the movements are overcome and redirected rather than relied upon to accomplish the adjustment.

We can not, however, be completely satisfied with mere negation. When we have accumulated the evidence to show that there can not be a direct relation between the sensations derived from irregular eye movements and the final completed percept, we must, on the other hand, recognize that there is the closest possible relation between the final adjustment and the complex percept of position in depth of the object fixated. In other words, the perceptual process and the movement are ultimately brought into harmony, though it is obvious that this harmony is obtained through effort and involved many irregular and conflicting factors. That there should be an ultimately successful binocular adjustment, in spite of the conflicting tendencies shown in the results above described, is the strongest argument for the recognition of a relation of fundamental importance between perception and movement. Furthermore, there can be no doubt in the light of the facts described in this

paper that the binocular adjustments differ in complexity and in the degree of effort necessary to attain them from certain simpler forms of adjustment.

In attempting to explain the complex forms of binocular adjustment we must recognize the fact that the adjustments themselves are in response to some demand which is of superior importance in individual life to the elementary tendencies which they overcome. The natural temptation will immediately arise to dispense with the whole question here involved by saying that the binocular motor adjustments are controlled by the retinal images. This will serve very well as a short formula if we wish to discuss merely the relation between sensations of movement and retinal sensations. It is undoubtedly true that the retinal sensation is in a certain sense the controlling factor in the total binocular fusion. It is only when like stimuli act upon the two foveas that the eyes can come to rest and the converging of the lines of regard as a condition preliminary to holding the two eyes fixed upon a certain point in spite of their natural tendency to move together in a lateral direction, is undoubtedly related to the superior significance in experience of the retinal sensation from the two foveas.

The short formula is, however, incomplete until some clearness can be reached as to the nervous organization by which the retinal excitations are related to movement. Sherrington[1] has made it clear that the retinal excitations are sources of independent central processes. He has further called attention in his book *The Integrative Action of the Nervous System*, pp. 385, *et seq.*, to the fact that the fusion of these independent central sensory processes is due to their union as they pass to the motor centers. Experiments on central localization have shown in agreement with the functional fact reported in this paper, that the movements in the two eyes which result from the stimulations of the occipital visual area are of the type described above as sympathetic lateral movements; that is, whenever this first cortical area in the occipital region is stimulated there is a tendency for the two eyes to move laterally in

[1] Sherrington, 'On Binocular Flicker and the Correlation of Activity of Corresponding Retinal Points,' *British Journal of Psych.*, Jan., 1904, pp. 26–60.

the same direction. It is only when one of the higher association centers situated further forward in the cerebrum is aroused to action that there is any tendency toward convergent movement of the two eyes. Convergent movement is thus obviously dependent upon a higher form of associative activity in the central nervous system than that which is demanded for mere lateral movement of the two eyes in sympathetic activity. Thus we see that while the short formula which holds that retinal images guide the adjustment of convergence and divergence is satisfactory for the statement of the contrast between sensations of movement and retinal sensations, it is by no means acceptable as a complete statement of the whole formula of fusion. Fusion in this case evidently involves a coördination of impulses of an elaborate associative type. If that coördination is of the simple type provided for in the first visual region of the cortex, the motor adjustment will be of the more elementary form. If, on the other hand, convergent coördination is present, this appears as a higher type of coördination than that which is provided in the simpler sympathetic adjustment, and for the more elaborate coördination higher centers must be drawn into action and correspondingly a higher form of experience must be expected.

We are thus led from our considerations of the relation between retinal images and movement process to recognize the fact that after eliminating sensations of movement we must recognize the paramount importance of motor adjustments in an entirely different sense. The important question is one of coördination of impressions in the development of more and more elaborate forms of response. It is not a question of how fully we are informed through sensations of the adjustments after they are made, it is rather a question of how elaborately we are able to respond to sensory impulses through higher forms of associative coördination. Experience will thus be explained not so much by the factors which enter into it as by the forms of elaboration to which these factors may contribute. The movement is not significant because of its peripheral elements which, as this report has shown, involve an oscillation backward and forward with a resultant tendency

toward gradual convergence or divergence. The movement is rather significant because as a total form of activity it is worked out as a response to certain complicated sensation processes which are themselves unified and fused in experience in the development of the unitary motor adjustment. The unity of experience is not to be described by regarding the one group of sensation factors as in control and the other elements as clustered about the dominant sensations. The whole experience is to be regarded rather as a succession of associative processes in which the end of the process may very properly be described as a motor adjustment to all of the sensory elements. The stages of that process may be variously complicated by monocular tendencies and sympathetic tendencies in one direction or the other. But these secondary or complicated elements are all of them significant merely as indications of earlier stages of coördination and fusion, not as contributing any positive factors to the present fusion. Indeed, there are many evidences that the preliminary motor adjustments are not important for the final coördination, but mere incomplete and partial phases of the total process. Thus, a consideration of the time required to correct one of the irregular movements which appears whenever one eye is distracted from the path of convergence in order to sympathize with the other eye is so short that there is no possibility of clear perceptual consciousness intervening between the execution of the movement and its correction. There seems to be a momentary oscillation between phases of adjustment. The first tendency is for the two eyes to move sympathetically in a given direction. Before this tendency can be consummated in any such way as to come to clear consciousness and invite a voluntary change in the direction of one of the eyes, a second phase of movement sets in which obeys the demands of higher coördination. Taken by itself, each phase of sympathetic and corrective movement seems to be an involuntary or reflex adjustment of the eye. On the other hand, when we consider the total process of conscious perception and motor coördination, we recognize that the essence of the process is not in the single factors but in the combination. As we saw in Fig. 117, the mastery of the sym-

pathetic form of movement in the course of a series of convergent and divergent fixations becomes more complete as the series of adjustments proceeds. It would seem, therefore, that the clearer and clearer perception of a given situation results in a more and more affective subordination of the discordant adjustments to the demands of the total adjustment. The total process is thus shown to be a higher form of coördination than any of its elements and to stand in a very different relation to conscious experience.

If for any reason the coördination is delayed, the separate factors may assert themselves. Thus, in the adjustment indicated for Fig. 116, the most characteristic fact in the subject's experience is the utter confusion of his visual percepts. It is quite impossible for him to guide his visual activities because the single factors assert themselves in such a way as to prevent final coördinated activity. Again, the observation that prior to the final adjustment there is a clearing up period in experience is a fact of the same type. These cases of incoördination or confusion form the most productive starting point for an explanation of the nature of perceptual fusion. Whenever one is confronted by a mass of experiences for which he has no definite mode of response, that mass of experiences is confusing just because it distracts him in such a way as to attract a great variety of conflicting adjustments. He tends to move now in one direction, now in the other, without succeeding in performing completely any single reaction. We may say of his movement on the one hand that it is uncoördinated. We may say of his experience on the other that it is entirely lacking in unity and in clearness. Nor will the unity and clearness of experience and the corresponding coördination of behavior result by any mere adding together the different elements of sensory experience or motor response. The fusion must be worked out by bringing about such a relation between the different phases of adjustment that they shall all be included and combined into a new form of coördinated completeness which shall have a unity of its own type, a unity superior to that of the elementary forms of sensation and activity which it embraces.

Such a formula as this is applicable in the discussion of all

kinds of perceptual development. There can be very little doubt that an infant finds itself overwhelmed with a great mass of sensory experiences by which it is constantly distracted. The few forms of adjustment which are clearly worked out through instinct in the infant are the only clear-cut forms of adjustment which it has and its earliest attention is evidently directed toward the objects to which these instinctive coördinations apply. Undeveloped adult percepts certainly illustrate the formula of incoördination of factors. Thus, if one looks at a new and complex visual pattern he fails to recognize clearly the complex figure because the mass of lines is so distracting that each draws his attention away from the other. Both in the case of the infant and the confused adult the surest method of attaining a clear percept of any given phase of his environment is to gradually work out a practical adjustment in which activity and sensory experience shall be unified by subordination of most of the elements to a few dominating factors. That is, instead of making a succession of reflex responses to a great variety of different factors, the subject must ultimately reject some of these reflex tendencies. If they are so strong that they tend to assert themselves in spite of the dominating center upon which he would converge, he must then work out a higher form of coördinative adjustment whereby he shall be able to recover from the strong reflex tendency which has led him astray. He must, in short, by some means or other succeed in overcoming the great manifold of distracting experiences. When he has thus succeeded in withdrawing from many avenues of impulsive adjustment, he may ultimately work out a form of adjustment which will be of a much more unitary and stable order. He will then find that there has been going on in his sensory experience a process of selection whereby certain factors have been distinctly subordinated to a few dominant elements of experience.

The dominant elements in such a process can not now be described as having asserted themselves through the complete suppression of the other elements; nothing is suppressed in the sense of being eliminated. The sensory processes can not be shut out, and the energy poured into the central nervous system

by the minor sensation can not be ignored. The selection of the particular centers of experience and adjustment is rather a matter of relations in which all factors are included. The adjustment instead of being merely negative includes the total individual. The concentration is not merely a matter of sensory elements, it is not merely a matter of muscular adjustments; it is a matter of general relating and placing of factors in advantageous relations.

There has been in the discussion of perceptual fusion in psychology some tendency to confuse two distinct characteristics of percepts which characteristics have, so far as their conditions are concerned, entirely different types of origin. First, every percept has the characteristic of inclusiveness, and in the second place every percept has unity. The inclusiveness of a percept is ordinarily much larger than the descriptive analysis of percepts by introspection would admit. One does not ordinarily recognize, for example, in the binocular adjustment which we have been studying, the natural tendency to recognize a great variety of objects in the lateral regions of vision, although these apparently ignored objects undoubtedly enter into the determination of eye movements. One does not recognize through any introspective analysis the fact that when a sympathetic movement is performed by the two eyes there is an increase in the confusion of retinal images sufficient to call for an immediate readjustment. One does not recognize explicitly, as even the most ardent defenders of movement sensation theories are prepared to admit, the sensations of movement which come from the muscles of the eye or the sensations of contact which come from the surroundings of the eyeball during its adjustments. Indeed, if these various factors which are unquestionably contributory to the total percept came into any clear recognition, they would constitute a disturbance of the perceptual process. They are included but are not recognizable factors. They are fused with the chief elements which in this case consist of the retinal elements, but their fusion is of such character as to subordinate them to the main sensations. The main sensation would have no perceptual setting if it were not for these surrounding sensation factors.

Inclusiveness thus emphasizes the great variety of factors entering into percepts. In sharpest contrast with the inclusiveness of percepts stands their unity. The more factors included in a percept the more obvious the demand that they shall be reduced to a single coördinated system. Unity must be sought elsewhere than in the manifold of sensory factors. Unity is, accordingly, wrought out of experience by counteracting the tendencies that grow out of wide inclusiveness. Inclusiveness may be regarded as the primary character of consciousness, and in so far as fusion is used to describe the inclusiveness of a conscious state we may say that inclusiveness is the most elementary fact in mental life. It is certainly more elementary than concentration on single clearly defined experiences. A single clearly defined experience is a late product of perceptual development. It comes as a result of the narrowing down of inclusiveness; it does not in any sense of the word arise by any process of mere addition of factors to each other nor by a mere ignoring of factors.

The notion of addition or subtraction should be eliminated altogether from the discussion of perceptual fusion. The only concept which is of any value in the clear explanation of perceptual unity is the concept of coördination. This concept is one which gives us the justification for treating the processes of perceptual fusion as processes of unification, and unification, as will be seen from the foregoing discussion, is totally different from inclusiveness. When one succeeds in building up in his experience a compact percept, he has not succeeded in doing this by bringing into consciousness factors which were not there at the outset, nor has he attained it by bringing together factors which formerly existed apart. He has done it in most cases by utilizing certain adjustments which were all present at the same time but mutually incompatible, and he has developed a form of adjustment which can in some measure reconcile the incompatible factors. Consider, for example, in terms of the material presented in the earlier part of this paper the mass of retinal, muscular and tactual sensations which are involved in any act of binocular convergence or divergence. Consider, on the other hand, the clearness with which con-

sciousness moves to its perceptual goal in spite of all of the elements of experience. So far as this binocular adjustment of convergence is to be described in terms of inclusiveness, it comprises a great number of distracting and unnecessary elements. When, on the other hand, we recognize how the adjustment of the two eyes overcomes all of the distractions that precede it, we see how closely related are the final motor adjustments of the eyes to our clarified and definite spatial organizations of experience. We bring all the data of sensory experience together and recognize in one act of consciousness the distance between a remote point and a near point at the same time that we accomplish a careful adjustment of the two eyes upon the near point. Both processes involve a subordination of many of the elements of the environment which are constantly impressing the retina and many of the muscular adjustments which arise from the collateral and unnecessary tendencies of eye movement. This perceptual experience is, however, a compact unitary process which has a certain definite content about which all of the other elements are related, and it derives through its unity and through the compactness of its various elements certain characteristics which the central, highly clarified elements could not possess unless all of the secondary factors had been properly coördinated with, or better, subordinated to them.

The point which we fixate we recognize as having position in space, as having relation to the other factors that enter into visual experience, and the whole group of factors is recognized as completely mastered in a single unitary percept. The unity is by no means the same as the inclusiveness. It is a unique and highly developed fact in which the different sensory elements are made to contribute to a single clearly marked phase of conscious experience.

It has frequently been observed that the movement of binocular coördination in infants is later in its development than the sympathetic lateral movements of the eyes. It is probably true in view of these observations that there is a certain period of infancy during which recognition of position in depth is undeveloped. We certainly can not assume that the infant whose two eyes are not yet coördinated in binocular adjustment

is deprived of the mass of retinal sensations that come to him from the ordinary impact of light upon his two organs of sense. There must be unlimited confusion in his experience because of the tendency which many points in the field of vision have to attract lateral movements to themselves, and when these lateral movements are undertaken they not only do not prove satisfactory, because they bring new confusing elements into experience, but they furnish a motive for experiments in new types of ocular adjustments which are distinct from those which arise easily and reflexly. The infant, in other words, must have a vague consciousness that his adjustments are increasingly inefficient, when he moves his eyes in simple lateral movements in the presence of two bright points which lie at different distances from him. To hold that the infant is in any sense of the word clearly conscious of what we have here stated in an abstract logical form is, of course, a fallacy which can easily be guarded against by reformulating our statement and putting it in impersonal terms. We may say that there is confusion in consciousness from the time the infant comes in contact with two bright points at different distances in depth. This increasing confusion must continually excite new motor adjustments until by some chance a form of motor adjustment appears which will bring the two foveas into the familiar relation to the bright points. The analogy suggested in Fig. 115 has already been pointed out as perhaps the best analogy with which to inforce this point. If the infant were not capable of recognizing the confusion in experience in some fashion or other, he would simply go forward with the sympathetic lateral movements which are the easy forms of adjustment. There is no reason to believe that he would ever rise above this level any more than the subject reported in the photographs in Figs. 105 and 106 who, having no retinal images to become confused, has no motive whatsoever for undertaking new forms of visual adjustment above those of the simple sympathetic type.

The confusion in the earliest stages of impression must be recognized as a motive for effort until there shall be substituted for the confused mass of experience a more satisfactory or highly selected type of experience. This organized mass of

experience will be no less inclusive than at first, but it will be more completely unified. Furthermore, it should be noticed that the rearrangement is not a merely static process. It does not consist in the adding together of sensory factors which are alike in quality, but there is a progressive combination of all of the different factors of sensation and of activity until the reflex tendencies aroused by different sensations shall be combined into an all-inclusive unitary tendency. Such a formula as this does not emphasize the sensory qualities of two retinal stimulations, it emphasizes rather the importance and necessity of a single adjustment which shall bring together stimulations through a single motor adjustment. The formula is both sensory and motor. It is a formula dealing with coördination of elements rather than with the elements themselves. The general grounds for the adoption of such a formula as this have been dealt with by the writer in an earlier paper.[1] The formula serves so admirably to explain the results in this series of photographs and at the same time clears up so completely the difficulties which interfere with any effort to give a purely analytical account of binocular fusion, that the present discussion must be accepted not merely as an application but also as a confirmation of the position assumed in the earlier paper.

[1] Vol. No. I., New Series, *Yale Psychological Studies*, pp. 199–266.